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UNDERWATER POWER SOURCE STUDY

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This report is concerned with the development of an ultra low cost underwater propulsion unit that can horizontally deploy 500 -1000 feet of sonobuoy cable at depths between 500 and 1000 feet. A trade-off analysis shows that the best system is based on a gas driven water pulsejet (hydropulse) and that the best source of gas is a reaction between Lithium aluminum hydride ( $\text{LiAlH}_4$ ) and seawater. The fuel		

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cost for 15 minutes of operation is about \$2.00.

A design for the pulsejet engine was then prepared (the drawings are in Appendix C) together with reaction rate measuring equipment. This culminates Phase I of the contract.

PREFACE

This program had as its goal the identification of a small low-cost underwater propulsion device that could be used to horizontally align a horizontal sonobuoy array. This effort closely parallels one in which Payne, Inc. recently participated with the U.S. Navy personnel at the Naval Ocean Systems Center (NOSC) in San Diego, California. The results of that effort are presented in Reference 1. The evaluation of other devices during that program forms a large part of the basis for the final selection on this program.

The project manager for the Naval Air Development Center, Warminster, Pennsylvania was William H. Hazlett, Jr. The principal investigator at Payne, Inc. was Peter R. Payne. The design effort was accomplished by Harold L. Newhouse, and Edward Dick performed the testing and evaluation for the components.

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<sup>1</sup>McCartney, J.F., Shipman, W.H., and Payne, P.R. "Low Cost Underwater Propulsion", Proc. of AIAA/SAE/ASME 17th Joint Propulsion Conference, Colorado, Springs, Colorado, July 1981.

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SUMMARY AND INTRODUCTION

The tactical ASW forces of the U.S. Navy are continuously seeking means to improve their performance. Deployment time of an acoustic sensor is significant in the effectiveness of the system. As a means of improving this deployment procedure, reducing the time to become operational, and providing the ability to redeploy a system after a period of operation, a small, inexpensive, expendable thrust device is being considered as a candidate for the source of power.

Covered in this report are results of the Payne, Inc. effort to identify a likely contender for this low cost energy source and thrust device that would meet the constraints imposed by the contract. The requirements were:

- a. be capable of operation at a minimum depth of 500 feet (150M) with a design goal of 1,000 feet (300M);
- b. Be capable of continuous operation for a minimum of ten minutes with a design goal of five additional minutes on an intermittent basis on command;
- c. be capable of producing a nominal thrust of three (3) pounds for the entire period of operation;
- d. be capable of being packaged in a cylinder with a maximum diameter of 4.75 inches (12.07 cm) and a total volume of 60 cu. in. (0.983 l).

In addition to the above, it was required that a metallic hydride be one of the power sources investigated.

A literature survey was conducted to identify previous work applicable to the task at hand. Because of the time available copies of all documents that might apply to this study could not be obtained. Within the program constraints of time and costs, however, it is believed that most of the significant data have been reviewed and the applicable portions are discussed in the appropriate parts of the text of this report. A bibliography of these articles is presented as Appendix A. As the program continues additional references undoubtedly will be received and if any information is presented to confirm or significantly affect the conclusions of this program, copies will be provided to the Navy Project Engineer.

An evaluation was made of the candidates for the segments of the low cost underwater propulsion system. As a result of the analysis of data contained in existing literature and recognizing the time and cost constraints of this program, it was found that the field of choice for viable contenders was quickly reduced. The complete propulsion system was divided into its principal components: Energy Storage, Energy Conversion, and Thrust Producer.

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As a baseline a system consisting of a battery, electric motor and propeller was selected. This system was considered well within the state-of-the-art functionally even though its size might violate the desired volume requirement.

The results of the evaluation program concluded (as did Reference 1) that the most efficient Energy Storage means was lithium metal but that for a practical system Lithium Hydride and Aluminum was the most promising contender. The test plan to develop the necessary data for a gas generator is presented in Appendix B.

To convert the energy of the pressurized gas into usable power no system was found superior from a cost and simplicity standpoint to that of a pulsating jet of gas and consequently a pulsejet device was designed to fill this requirement. The operation and performance analysis of this device is presented in the text and the design drawings are presented in Appendix C. The test plan for evaluating the capabilities of this device is included in Appendix B.

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EQUIPMENT EVALUATION AND SELECTION

The complete thrust device may consist of three principal components: Energy Storage system, Energy Conversion system, and Thrust Producer. It is reasonable to first look at contenders for each major component to determine what might be the most satisfactory selection. In the end the selected component must be integrated with the other two components to form an efficient operating unit.

The concept of using a low cost propulsion device for deploying a multi-element hydrophone array is in its infant stage. Specific restrictions as to cost, size, weight and performance are not firmly established. As the concept is now envisioned some criteria has been established as targets for guidance purposes. Deviations from these targets must be evaluated in terms of the gains offered by allowing the deviations. In the end, obtaining a system in the general vicinity of the design targets that can be used as the basis for the projection of data to larger or smaller systems, obtaining hardware for evaluation purposes and applying the study of this concept to possible applications would appear to be the primary benefits that might evolve from this effort.

Along with the contract constraints outlined in the Summary and Introduction it was decided at a meeting with Navy program personnel that a basis for cost estimating might be the production of 5,000 units per year and that trade-off studies from other programs should be used where applicable to avoid repeating that effort. Utilizing the results of these other studies eliminated duplication of their effort and allowed resources to be concentrated on portions of this program, such as component design and application, that are considered more significant to a successful conclusion.

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PROPULSION SYSTEM

For this program, cost has been identified as one of the more significant trade-offs. If cost were of secondary importance then a larger number of options would be open to the designer in the selection of a propulsion device. As outlined in Reference 1 (a joint paper by NOSC personnel and Payne, Inc. personnel) most state-of-the-art alternatives for underseas propulsion systems are limited to expensive and complex systems. Included in this expensive and complex category, and consequently eliminated for selection on this program, are such systems as magnesium-silver chloride seawater battery with electric motor, reserve-electrolyte zinc-silver oxide battery with electric motor, and the Otto Fuel II open cycle engine. Even more expensive than these state-of-the-art systems and still under development are the aluminum-silver oxide battery with high performance electric motor and the Stored Chemical Energy Propulsion System (SCEPS) (Reference 2).<sup>2</sup> Another advanced system under development is the reserve electrolyte Lithium Thionyl Chloride Battery System (Reference 3).<sup>3</sup> It is likely to provide greater density and lower cost than the previous alternatives. The last three systems still in development however are not anticipated to achieve total procurement cost in the target range desired for the device sought here (less than \$500 with ultimate cost approaching \$100). Therefore these devices are eliminated from possible selection.

Of somewhat parallel interest is the effort being expended for energy storage studies and development for domestic uses. These include new battery developments presented in Table 1. These batteries also can be eliminated from further consideration here because of cost, weight and volume.

Although we must look at each segment of the propulsion system (Energy Storage, Energy Conversion and Thrust Producer), we must also look at the combination of these for a more complete answer. Obviously, a low cost energy storage device to be of any value must be married to an equally suitable energy conversion system.

Energy storage devices considered possible candidates are listed in Table 2. Candidate devices for the energy conversion system are listed in Table 3. The thrust producing candidate devices are listed in Table 4.

As indicated it is not practical to consider each component of the propulsion system entirely alone. The logical combinations of the above components were organized into viable complete propulsion systems. These candidate systems as studied in Reference 1 were evaluated on the bases of

<sup>2</sup>Gottfredson, R.K. "Lightweight Torpedo Propulsion Systems", Paper 79-1335, AIAA/SAE/ASME 15th Joint Propulsion Conf., Las Vegas, Nevada, June 1979.

<sup>3</sup>McCartney, J.F., Shipman, W.H. "Water Cooled Bipolar Battery Apparatus", U.S. Patent No. 4,152,492, May 1979.

weight, size, risk and cost. These are all factors of interest in this study and the rejection criteria found in the previous study were considered valid for our selection purposes. Table 5 presents the candidates and rejection criteria as generated in the Reference 1 study.

TABLE 1. BATTERIES UNDER DEVELOPMENT FOR DOMESTIC STORAGE SYSTEMS <sup>4</sup>

Battery Type	Operating Temperature (degrees Celsius)	Energy Density (watt-hrs/kg)	Power Density (watts/kg)	Est. Cycle Life	Est. Cost \$/kwh	Est. Availability <sup>a</sup> (Year)
Lead-Acid Utility Design	Ambient	--	--	2,000	80	1984
	Ambient	40	70	>1,000	70	1982
Nickel-Iron	Ambient	55	100	>2,000(?)	100	1983
Nickel-Zinc	Ambient	75	120	800(?)	100	1982
Zinc-Chlorine Utility Design	30-50	--	--	2,000(?)	50	1984
Vehicle Design	30-50	90	90	>1,000(?)	75	1985
Sodium-Sulfur Utility Design	300-350	--	--	>2,000	50	1986
Vehicle Design	300-350	90	100	>1,000	75	1985
Lithium-Iron Sulfide	400-450	100	>100	1,000(?)	80	1985

<sup>a</sup>Prototypes or early commercial models

A variety of advanced types of batteries are currently under development for electric-utility storage systems and electric vehicles because the lead-acid battery probably cannot be improved much further. The table lists the properties of batteries that may prove superior. The most important criterion for storage in electric-power systems is long life: the ability to undergo from 2,000 to 3,000 cycles of charge and discharge over a 10- to 15-year period. For electric vehicles the chief criteria are high energy content and high power for a given weight and volume. (The dashes indicate that these criteria do not apply to electric utilities.) Both the utilities and vehicles will require batteries that are low in cost (preferably less than \$50 per kilowatt-hour of storage capacity), safe and efficient.

<sup>4</sup>Kulhammer, F. "Energy Storage Systems", Scientific American, Vol. 241, No. 6, December 1979, p. 62.

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TABLE 2. ENERGY STORAGE DEVICES

Water Reacting Metals  
Lithium Batteries  
Explosives  
Cryogenic Liquids  
Mono & Bi - Propellants  
Buoyancy & Gravity  
Compressed Gases

\* \* \* \* \*

TABLE 3. ENERGY CONVERSION SYSTEMS

Linear Expanders  
Rotary Expanders  
Electric Motors  
Combustion Engines  
Fuel Cells w/Motor

\* \* \* \* \*

TABLE 4. THRUST PRODUCING DEVICES

Pulsejet  
Propeller  
Pump Jet  
Glide Surface  
Electromagnetic Pump

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 TABLE 5. CANDIDATE PROPULSION SYSTEMS

CANDIDATES	REJECTION CRITERIA		
	<u>Weight</u>	<u>Size</u>	<u>Risk</u>
Series of Detonations U.S. Patent No. 3,229,458			X
Gas Activated Water Pulsejet (Water Reacting Alloy)			
Steam Activated Eductor (Li-SF <sub>6</sub> Heat Source)			X
Lithium Battery, Electric Motor and Propeller			X
Lithium/H <sub>2</sub> O Battery & Electromagnetic Pump			X
Buoyancy Vehicle (Glider)	X		
Flywheel and Propeller	X		X
Hydroduct (Alclo fuel) Ram Water		X	X
Hydroductor Engine Alclo fuel		X	X
Hydropulse (Molten LI + seawater)	X	X	
Solid propellant Gas Generator Expander Jet Propulsor	X	X	X
Rotating Barrel (Gatling-gun) and Gas Generator	X	X	
Gas Generator & Jet Tip Propeller	X	X	X
Cryogenic Propellant/Pulsejet	X		
Otto Fuel & HAP with Piston Expander			X
Laser Initiated Explosions (Gatling-gun)		X	X
Hydroturbojet (Li Reaction Chamber)	X		X

## GAS GENERATOR

It was apparent from the results presented in Table 5 that the most promising device is the gas activated water pulsejet. Accepting this selection, an evaluation of the component parts of the system were then re-evaluated. It was recognized that the gas could be supplied by a number of alternate methods.

There are really only four approaches to generating gas efficiently:

- a. Expand a liquid gas.
- b. React a substance with water to produce a gas.
- c. Decompose a compound.
- d. Cause two compounds to react and produce a gas.

Of these, only a, b, and c are practical if volume of the gas generating compound is to be minimized.

Any gas generated will, to a first approximation, conform to the law of ideal gases, i.e.

$$PV = nRT .$$

If P is expressed in atmospheres, V in  $\text{cm}^3$ , and T in degrees Kelvin, then n equals the number of moles of gas present and R equals 82.07. From this equation it is clear that the volume of gas produced at a specified pressure and temperature is proportional to the number of moles present. If we wish to compare compounds for their volumetric efficiency as a gas generator, a simple function of density, molecular weight and moles of gas per mole of compound is:

$$\frac{n}{\text{cm}^3} = \frac{k\rho}{\text{MW}}$$

where  $n/\text{cm}^3$  = number of moles per  $\text{cm}^3$

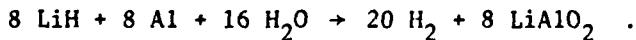
k = number of moles of gas produced per mole of substance

$\rho$  = density of compound in g/cm

MW = molecular weight of compound.

Table 6 tabulates  $n/\text{cm}^3$  for the leading choices of gas generating substances.

From Table 6 it can be seen that lithium hydride is the most volumetrically efficient of all of the simple compounds listed. It is interesting to note that by combining this compound with powdered aluminum in equal molar ratios, (about 8g to 27g) the high cost of the pure lithium hydride can be reduced and the hydrogen gas produced per cubic centimeter can be increased. When lithium hydride reacts with water, both hydrogen and lithium hydroxide are produced. The lithium hydroxide, in turn can react with the powdered aluminum to produce more hydrogen. The overall reaction is:



On the basis 12.72 grams lithium hydride mixed with 43.168 grams powdered

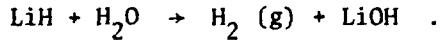
aluminum would produce four moles of hydrogen gas which, at STP, would occupy a volume of 89.6 liters, yet the volume of the aluminum and lithium hydride is only 32.3 cm<sup>3</sup>. By replacing the lithium hydride with elemental lithium, the volumetric efficiency is almost as good as calcium hydride alone. The overall reaction is now:



This means that about 3 1/2 grams of lithium metal mixed with 13 1/2 grams aluminum would produce one mole of hydrogen gas which by definition would occupy a volume of 22.4 l at STP. The volume of the two metals would occupy a volume of only 11 1/2 cm<sup>3</sup>.

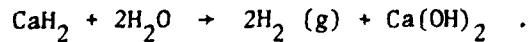
It is clear that the combining of lithium hydride with aluminum is the best method of getting the most hydrogen from the smallest volume of reactants and at low cost. But it must be understood that some of this advantage is lost when the engineering problems of introducing water into the reaction chamber are considered.

It is not surprising that Table 6 shows lithium hydride as first choice of the simple compounds. This compound has a molecular weight of 7.95 and a density of 0.78 g/cm<sup>3</sup>. The very low molecular weight compensates for the unfortunate low density. It reacts with water by the following equation.



From this equation and the gas law equation it can be calculated that at a depth of 100 meters, 1 cm<sup>3</sup> of lithium hydride would require 1.8 cm<sup>3</sup> water to produce 222.7 cm<sup>3</sup> hydrogen gas. But that is not the entire picture. The 2.395 grams of lithium hydroxide which is also produced must be dissolved and removed from the reaction site or the reaction will not go to completion. The amount of water necessary to dissolve the lithium hydroxide is about 18.9 cm<sup>3</sup>. Since high concentrations of the lithium hydroxide strongly suppresses the reaction rate between water and the lithium hydride, it must be removed in order to allow hydrogen production to proceed. The engineering complications of water introduction and lithium hydroxide removal from the reaction chamber must be taken into consideration if lithium hydride is to be used as a gas generator. In fact, all gas generating substances that rely on water to generate a gas have this same problem to some degree.

The third choice as seen in Table 6 is calcium hydride. If cost is a consideration then it becomes second choice since the second most efficient gas producer on a volumetric basis costs considerably more. Calcium hydride has a molecular weight of 42.1 and a density of 1.902 g/cm<sup>3</sup>. It is the high density that overcomes the high molecular weight and also the fact that two moles of hydrogen gas are produced on reacting it with water. The equation for the reaction with water is:



This equation shows that, like its lithium counterpart, fairly large amounts of water are needed to produce hydrogen. Unlike its lithium counterpart,

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TABLE 6. VOLUME OF GAS PER GRAM AND PER CUBIC CENTIMETER  
OF MATERIAL

<u>COMPOUND</u>	<u>n/cm<sup>3</sup></u>	<u>n/gm</u>	<u>H<sub>2</sub>O gm/gm fuel</u>
Equal Molar Lithium Hydride-Aluminum	0.1239	0.0716	1.03
Lithium Hydride	0.0981	0.1258	2.27
Lithium Aluminum Hydride	0.0967	0.1055	0.95
Calcium Hydride	0.0904	0.0475	1.71
Equal Molar Lithium-Aluminum	0.0871	0.0590	1.06
Liquid Neon	0.0595	0.0496	
Hydrazine	0.0525	0.0521	
Calcium Metal	0.0387	0.0250	0.90
Lithium Metal	0.0385	0.0720	2.60
Iron Penta Carbonyl	0.0382	0.0256	
Sodium Peroxide	0.0360	0.0128	0.23
Liquid Hydrogen	0.0347	0.4960	0
Calcium Carbide	0.0346	0.0156	0.56
Liquid Nitrogen	0.0287	0.0357	
Liquid Xenon	0.0236	0.0076	
Potassium Oxide "super"	0.0226	0.0106	0.19
Liquid Methane	0.0211	0.0498	

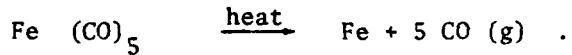
TABLE 7. SOME GAS SUPPLY SYSTEMS

	<u>Weight of Material, lb</u>	<u>Volume of Material, in<sup>3</sup></u>	<u>Estimated Weight of Apparatus, 1b</u>
Pressurized gas: helium at 5,000 psi	0.67	325	18
Liquid CO <sub>2</sub>	9.2	340	2
Fe(CO) <sub>5</sub> + heat → Fe + 5 CO	6.5	127	3
Burning rocket grain to form a gas	5.36	98	5
Hydrazine decomposition: $3 N_2H_4 \rightarrow NH_3 + 2.5N_2 + 4.5H_2$	2.3	65	1
Lithium Hydride plus free water: $LiH + H_2O \rightarrow LiOH + H_2$	1.35	50	0.5

calcium hydroxide is not very soluble. At zero degrees celsius only 0.12 grams will dissolve in 100 cm<sup>3</sup> water. In contrast, under the same conditions 12.7 grams of lithium hydroxide would dissolve. This lower solubility of calcium hydroxide would cause precipitation and hence the reaction between the hydride and the water would not be strongly suppressed. Its utilization still is complicated by the engineering demands of maintaining hydrogen pressure and transporting water into, and reaction products out of, the reaction vessel.

The fourth choice is liquid neon. It, like liquid nitrogen, presents all the problems of cryogenic substances. A liquid gas does not require moving water but does need heat for vaporization. Neon is the best of all liquid gases because of its high density. Liquid neon has a density of 1.2 g/cm<sup>3</sup> compared to the 0.804 g/cm<sup>3</sup> for liquid nitrogen. In the use of liquid gases, an alloy of lithium and aluminum external to the gas volume could react with the water to produce the heat necessary to boil the liquid gas. Its primary disadvantage is logistic. The problems of supply and storage are difficult. Of the liquid gases, nitrogen would be the only one not presenting logistic and storage problems since an air liquefaction plant would not be difficult to establish on site.

A fifth choice is iron penta carbonyl. This heavy liquid will at very high temperature decompose into elemental iron and carbon monoxide by the equation below.



The use of this compound is complicated by the need for a very high temperature decomposition chamber to produce the gas from the liquid carbonyl. This complication could be eliminated if a suitable catalyst could be developed. The n/cm<sup>3</sup> listed in Table 6 is a high estimate because the weight of a furance or thermite mixture to decompose the compound is not considered; it does offer the simplicity of being a liquid and does not need any complicated pumps to introduce water and remove reaction products while maintaining pressure.

From Reference 5 we find that an evaluation of some gas supply systems gave an indication of the relative weight of apparatus required. This evaluation is shown in Table 7. Since the weight of the apparatus can often be related also to cost, we can suspect that the lightest will possibly also be the lowest cost.

Based on the studies of References 1 and 5 and a current cost of materials at \$30/lb\*, it is concluded that the most promising method of storing

<sup>5</sup> DeVries,, G. "High Pressure Gas from Lithium Hydride and Sea Water", U.S. Naval Ordnance Test Station, AD 625513, December 1975.

\*It is anticipated that 30.14 gm of fuel will be required for 15 minutes, corresponding to a cost of roughly \$2/mission.

energy for the generation of hydrogen gas is to use lithium or lithium hydride along with aluminum. Previous work<sup>6,7</sup> has shown that it is feasible to provide this material in different shapes and with materials that allow more controlled reactions of the lithium, aluminum and water and the generation of the hydrogen gas to be produced.

Based on preliminary calculations it is estimated that the propulsion unit would require about 1,292 in<sup>3</sup> of gas at STP for 15 minutes of operation. This would theoretically require a volume of about 3.7 in<sup>3</sup> of solid material plus water for the 15 minutes of operation. (In practice, larger quantities of water are required in order to maintain a reasonable temperature.)

A feed water pump, driven by the pulsing of the pilot valve piston, will inject water into the gas generator at approximately the correct rate to produce one pulse quantity of gas. When Al is included in the initial composition, the end product ( $\text{LiAlO}_2$ ) is a solid and is simply allowed to collect in the bottom of the generator.

The internal design of the gas generator will include a gas collecting system which functions regardless of the system's orientation. Otherwise, excessive products of incomplete reaction might be injected into the gas stream and pass out through the tail pipe. This collecting system may be accomplished using a weighted intake tube which always seeks the upper portion of the generator, with a separator to keep out the major solid material particles. It is proposed that the solids be in pellet form so these and the water are free to migrate to the low side of the generator. The high thrust peaks of the pulsejet will keep the materials agitated. The solids may tend to migrate to the rear of the gas producer, but this is not seen as a major problem since the waste will travel there also.

The shape of the gas generator may be readily adapted to fit the available internal space requirements of the propulsion system package. Its location relative to the pulsejet is also not too critical, although care must be exercised to provide adequate gas supply lines to avoid any choking or timing problems with the pulsejet. The jet exhaust tube of the pulsejet need not be straight. If desired it could be bent to fit a particular packaging requirement.

As a part of Task II Payne, Inc. proposes to conduct experiments with the lithium and aluminum materials already on hand. These materials in their current form must be handled in a very low moisture environment. A glove box constructed at Payne, Inc. is available for transfer of the materials to the test device.

Measured quantities of the lithium/aluminum material and water will be mixed in the test device. The rate of generation of hydrogen will be determined and plotted against time. Using this data a test hydrogen gas generator will be constructed and evaluated.

<sup>6</sup> Beumel, O.F. Jr. "Hydrogen Generating Composition and Use", U.S. Patent No. 3,346,506, October 1967.

<sup>7</sup> MacKenzie, G.L., Mosher, P.R. "Hydrogen Gas Generating Composition and Method for the Same", U.S. Patent No. 3,674,702, July 1972.

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PULSEJET EVALUATION

The pulsejet incorporates the energy conversion and thrust producer sections into one unit. We can conveniently then evaluate these two major components together. The selection of the pulsejet configuration was based on the work of Reference 1 which compared this form of a propulsor to other types of devices.

Water Breathing Engines

An extensive amount of experimental work was carried out during the late 1940's on water breathing engines by Aerojet Corporation under a Navy contract (References 13 through 24). The engine, which Aerojet called the "hydropulse" engine was fashioned after the design of the German Vergeltungswaffe No. 1 (V-1 Buzz-Bomb Engine) that flew during World War II. The hydropulse engine appears to have the type of features necessary for this application. It is simple, size efficient, and can operate over a range of very low to very high velocities. The original hydropulse reacted molten lithium with seawater to produce a sudden pressure rise in a duct that expelled the water from the duct. The duct then refills under ram pressure, due to the forward motion, and lithium is injected again. One version which used reed check valves at the forward end to contain the thrust pressure and open automatically to permit rapid refilling, produced thrusts of 4500 N and a speed of 32 m/s and demonstrated a fuel consumption rate of 36 N of lithium per thrust kWh. This fuel consumption rate indicates that the fuel requirement for an 18 m/s, 6 minute run may be satisfied with 14 N of lithium having a volume of 2.6 liters. Additional volume must be allocated for the lithium melter, lithium injector, and the duct. With substantial development of the lithium supply and control portions of the hydropulse engine, the minimum requirements of this application may be met.

The fact that lithium had to be melted and then injected added a large amount of complication to the machinery of the engine. Also, lithium is extremely energetic on the basis of volume. These facts led Aerojet to investigate other water breathing engines. Aerojet's philosophy was "for every air-breathing engine there exists an analogous water breathing engine". This philosophy led Aerojet to the discovery of the hydproduct, hydroductor, hydroturbojet and a substitute for lithium fuel called Alclo fuel (a compressed mixture of aluminum and potassium perchlorate particles).

One type of hydropulse which received almost no attention was a solid fueled engine. It was investigated in a small way by Aerojet but given up due to problems with controlling the reaction. Aerojet surrounded a hydropulse duct with a cast sodium cartridge which is held tightly against a per-

<sup>8-18</sup> Aerojet-General Corporation Reports Nos. RTM-27, RTM-45, R60,R68, R69,R77, 387, 419, 727, 1106, 2462 (1946 - 1963).

<sup>19</sup> Gongwer, C.A. "Water Propulsion Devices Without Primary Rotating Machinery", presented at the Symposium of Hydraulic Jet Propulsion under the sponsorship of Navy Dept. Office of Naval Research and Bureau of Ordnance, 1950.

forated partition which adjoins a reaction chamber. The pulsing action is started by intermittent injection of water in a fine spray against the sodium cartridge. The advantage of a solid fueled hydropulse is that the machinery for the injection and heating of the fuel is eliminated thus simplifying the engine.

Another form of the hydropulse engine which did not receive analysis is the compressed gas hydropulse. With this type of hydropulse no water reacting fuel is used. Instead, a compressed gas is introduced into the barrel and allowed to expand pushing out the slug of water in the barrel. With today's high strength materials it might be practical to carry enough compressed gas to fulfill mission requirements. The advantage of using a compressed gas instead of a water reacting fuel is that thermodynamic losses during the expansion of the gas are minimized.

The hydropulse is an open-cycle engine and hence depth sensitive. The efficiency of the engine will degrade with depth.. However, the calculations have shown that even 10% efficiency is acceptable performance from a volume standpoint. The hydropulse should be applied to shallow depth applications not exceeding 200 meters unless pressure can be increased as depth increases.

In summary, the hydropulse engine is a simple, size efficient jet engine. In order to use the hydropulse, development work needs to be done in the areas of fuels and fuel delivery. The gas-water interface needs to be investigated in a basic way and the hydropulse's performance with depth evaluated.

### PULSEJET DESIGN

The pulsejet proposed for this application is designed to be used with a gas generator. The generator is fueled by lithium aluminum hydride or similar type material reacting with water and produces hydrogen gas under pressure.

The proposed pulsejet assembly is shown in Payne, Inc. drawing 329D15. This drawing and the detail components are included as Appendix C.

#### Operation Cycle

This propulsion system is a pulsed jet device. By means of a pilot operated valve, carefully sized to open at a specific pressure ratio and closed by spring forces, a charge of compressed gas is injected into the propulsion tube. Here the gas expands and forces a pulse of water from the discharge end. When the main gas valve closes the differential pressure across the water column eventually becomes negative, and an exhaust valve is "sucked" open; however a check valve prevents external water intake into the tube. The differential pressure stops the water column, causes it to reverse its flow direction and move toward the exhaust valve forcing the initial gas charge out past the check valve. During the period of time the exhaust valve is open a detent lock keeps the main gas valve from opening. As soon as the water column reaches the head of the expansion chamber it strikes the exhaust valve and forces it closed. This unlocks the main gas valve which has now built up a sufficient head of pressure to "pop" open and allow a new pulse of gas to enter the expansion chamber. The cycle now repeats.

#### Component Operation

Gas pressure is allowed to enter the main accumulator from the high pressure gas source through a needle valve. This needle valve limits the flow rate so the accumulator pressure build-up is delayed long enough to allow a period of time for the main gas valve to close after initial gas discharge. This period of time must be greater than the time required to discharge the accumulator pressure into the expansion chamber but less than that required for the discharged air to expand, the water column to stop and reverse direction and impinge on the exhaust valve head. This needle valve can be used to limit the cycle frequency below the natural frequency determined by that of the expansion/exhaust cycle.

The gas pressure builds up in the accumulator to a maximum equal to that in the gas source. The total accumulator volume is that in the main accumulator section plus the volume behind the pilot valve and the connecting passageway. As pressure builds in the accumulator it bleeds into the space behind the pilot valve. Here the pressure acts on the pilot valve piston. Besides overcoming the O-ring friction, the initial pressure causes motion which forces trapped air from behind the pilot piston into a passage connecting with the exhaust valve positioning piston. If the exhaust valve is open then it is forced to move to a closed position by this low pressure air. Note: this portion of the pilot valve motion occurs only on start up.

The design of the pilot piston is such that after start-up the return motion is damped by the small clearance between the piston and cylinder bore so that the air is partially trapped. This delay should be sufficient to eliminate excursion of the piston into this area during normal operation but on shutdown the trapped gas will bleed off to provide a new charge on the back side of the pilot piston for the next start-up if it is required.

As the pressure builds up in the accumulator and behind the pilot valve, the pilot valve moves to the right (as shown in drawing 329D15). The piston contacts the shoulder on the stem which limits the piston travel until the pressure is high enough to open the main valve. As soon as the main valve cracks open, the pressure differential across the effective piston area decreases reducing the force that was holding it closed. The pressure on the pilot piston forces the valve wide open dumping the "slug" of air into the expansion chamber. The pressure bleeds off the back side of the pilot valve and the springs force both the main gas and the pilot valve to the closed position. A new charge of gas starts to build from the flow through the needle valve.

The air in the expansion chamber accelerates the water in the tube producing a propulsive jet from the discharge end. After the pressure in the expansion chamber reaches ambient the inertia of the water column causes its motion to continue until the differential pressure across the water column (created by the now lower than ambient chamber pressure) arrests the water motion. This low chamber pressure creates a "suction" on the exhaust valve and it opens. When the exhaust valve opens a plunger, moved by a cam on the end of the exhaust valve stem, engages a detent in the main gas valve stem and locks the main gas valve closed. A one-way valve in the exhaust system prevents water entering the exhaust port.

As the water column reverses direction and accelerates toward the head of the expansion chamber it pushes the trapped gas past the exhaust valve and the one-way valve and out the exhaust port. When the water reaches the exhaust valve head the impact is sufficient to push the exhaust valve closed. This motion allows the lock plunger to disengage from the main valve stem and the main valve is then free to open. Normally at this time the pressure will be built up so that the main gas valve "snaps" open; however if the needle valve adjustment restricts the flow into the accumulator sufficient to delay this build-up then there could be a momentary pause before the next pulse. As soon as the main valve opens the next charge of gas is injected into the expansion chamber and the cycle repeats.

Since this pulse jet is intended to operate with high pressure gas from a gas generator which requires an injection of water, a pump has been incorporated on the main gas valve stem. Each time the main gas valve "pops" open a small charge of water is injected into the gas generator at a controlled rate to produce the hydrogen gas.

#### Component Performance Calculations

These calculations are based on the following assumptions:

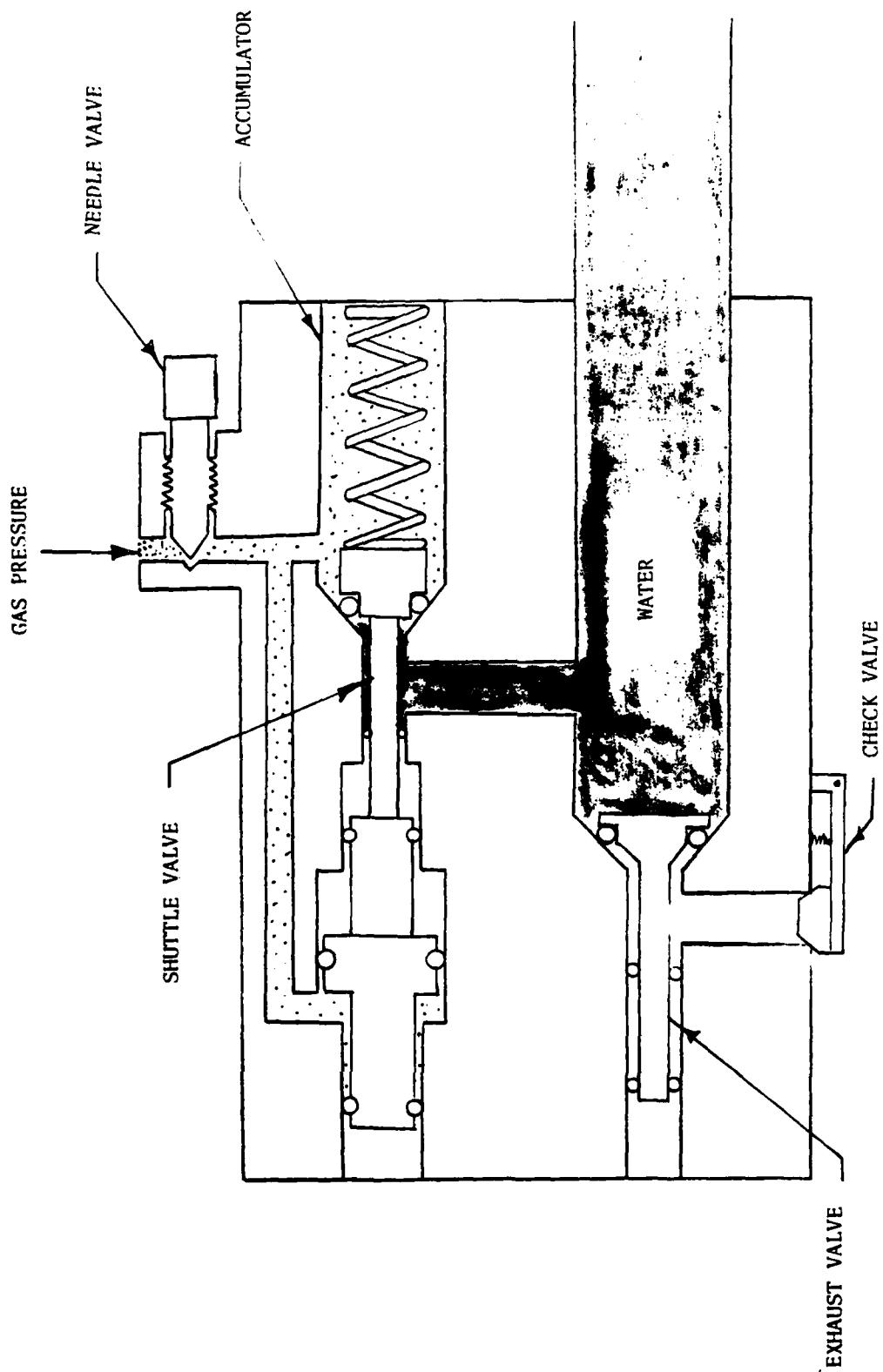


Figure 1.

Step #1. Time for accumulator to reach discharge pressure is adjusted with needle valve.  
This allows pulsejet cycle to be completed before next discharge.

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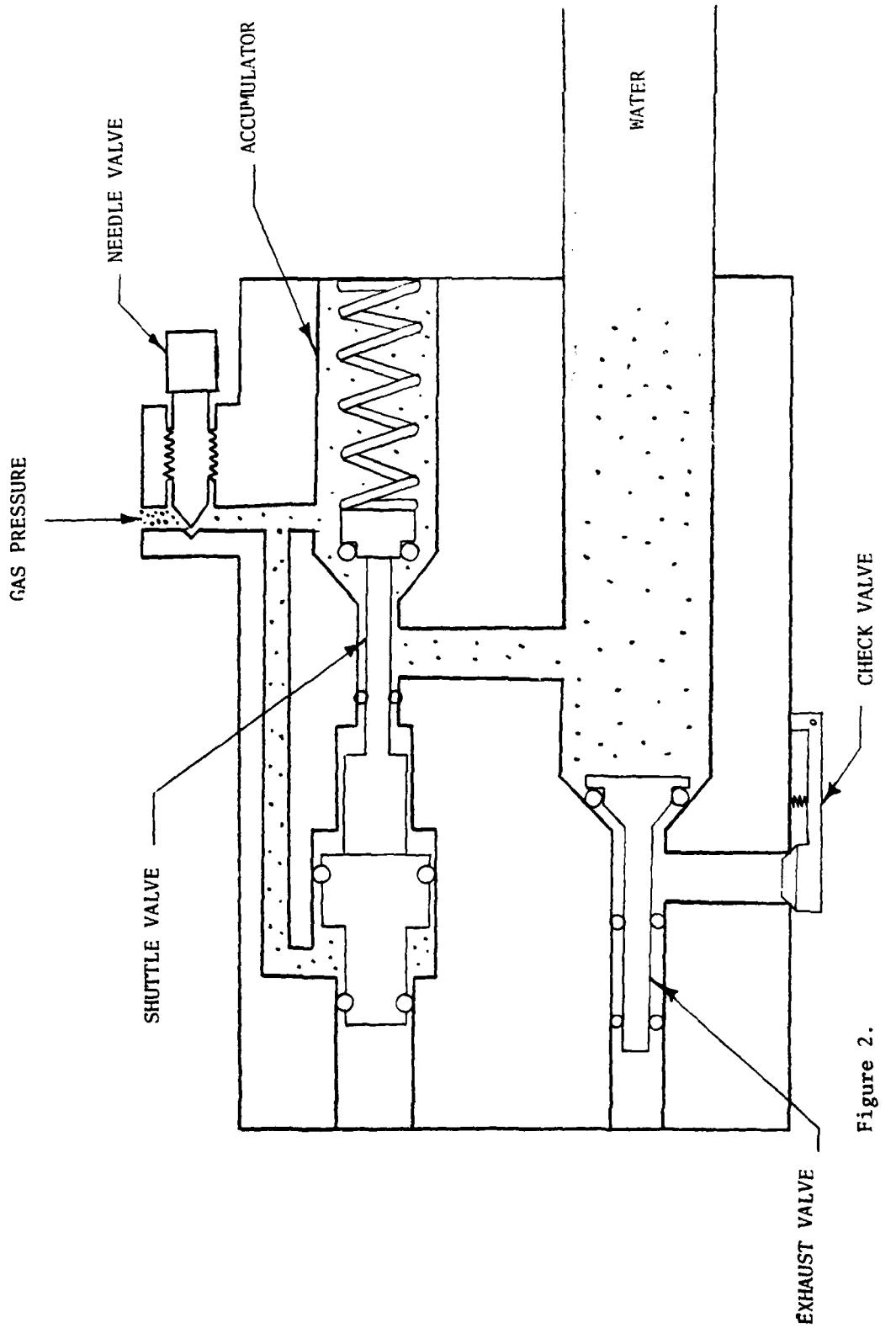


Figure 2.

Step #2. At maximum accumulator pressure, spring force is overcome and pressure discharge accelerates water column out of duct.

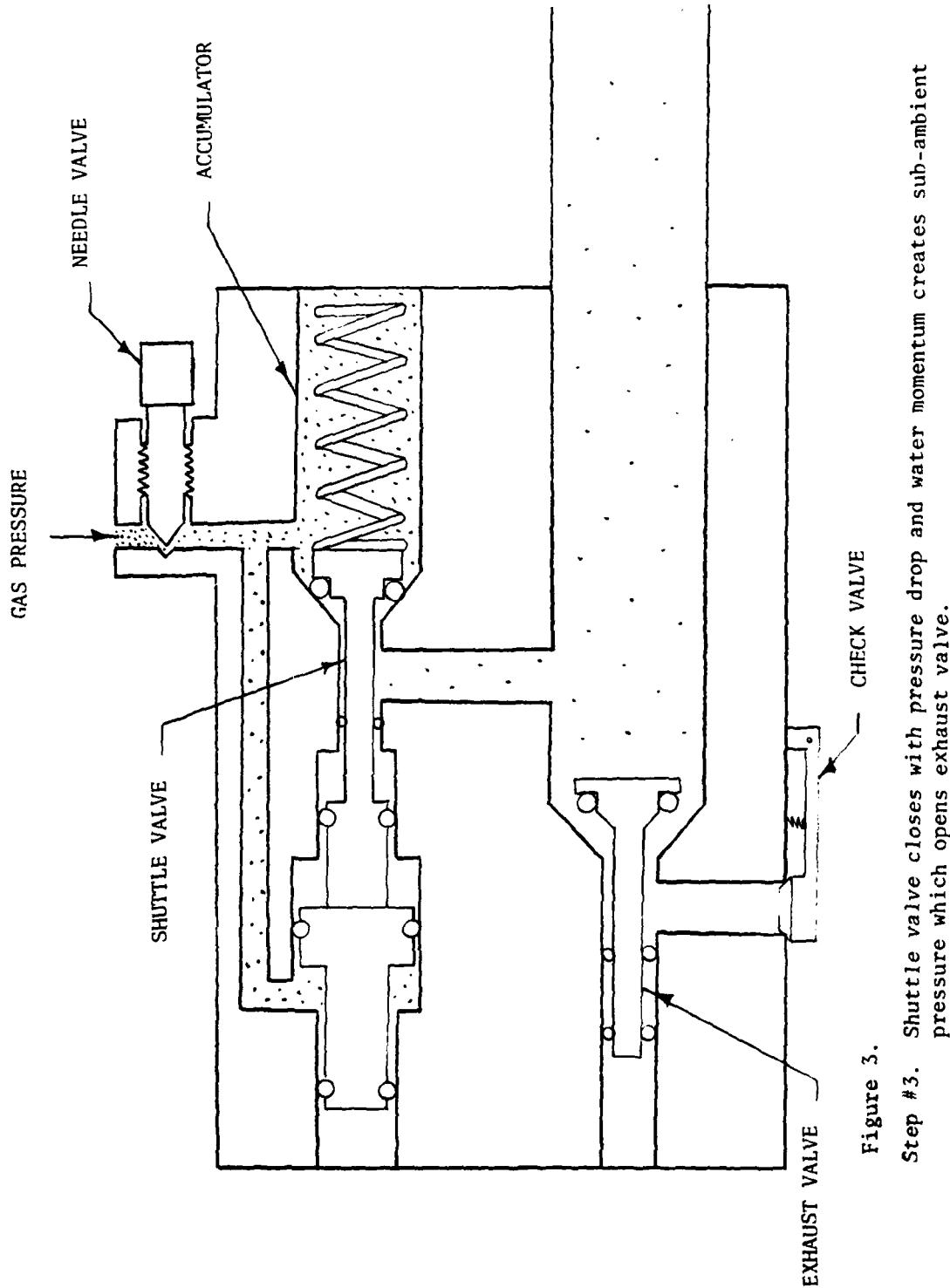


Figure 3.

Step #3. Shuttle valve closes with pressure drop and water momentum creates sub-ambient pressure which opens exhaust valve.

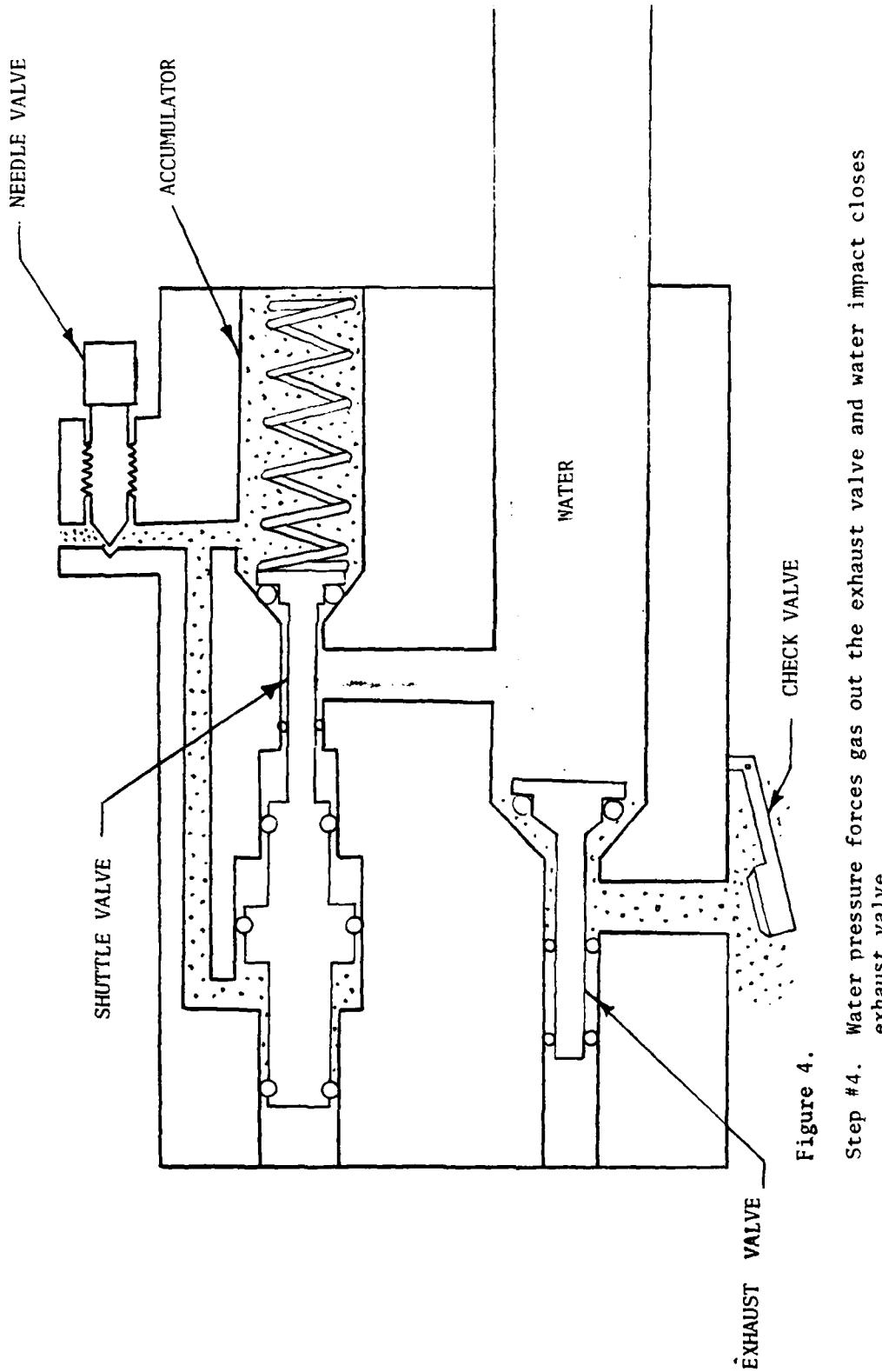


Figure 4.

Step #4. Water pressure forces gas out the exhaust valve and water impact closes exhaust valve.

1. Unit operating at sea level.
2. Gas supplied at 500 psig.
3. Approximate total gas stroke equals 6.0 inches with 3.0 inches expansion and 3.0 inches at or below ambient pressure.
4. Operation at greater depths may be accomplished by maintaining the gas source pressure relative to the depth pressure at approximately 500 psig.

#### Accumulator Volume

The formula for average thrust is

$$T_{av} = \frac{1}{4} \rho x_0^2 \omega^2$$

where  $T_{av}$  is in pounds

$\rho$  = mass density of water (slugs/ft<sup>3</sup>)

$x_0$  = the semi stroke (ft)

$\omega$  = oscillation frequency (rads/sec)

$$\therefore \omega^2 = \frac{4T_{av}}{\rho x_0^2} = \frac{4 \times 3}{1.00 \times (\frac{1}{4})^2} = 96.5$$

$$n = \frac{\omega}{2\pi} = \frac{9.82}{2\pi} = 1.56 \text{ Hz.}$$

The gas volume in the duct at STP is 0.92 in<sup>3</sup>. . Thus the total volume required for 15 minutes operation is

$$0.92 \times 1.56 \times 60 \times 15 = 1292 \text{ in}^3 \text{ at STP}$$

$$= 1292 \times \frac{14.7}{514.7} = 36.9 \text{ in}^3 \text{ at 500 psig}$$

$$= \frac{36.9}{1.56 \times 60 \times 15} = .026 \text{ in}^3/\text{stroke at 500 psig.}$$

This calculated volume is so small that it is impractical to limit the total volume to this amount. It is anticipated that the pulsing action of the main valve will be rapid enough to limit the volume of gas passing to approximately this amount by restricting passage sized from the "out-lying" volume of the pilot cylinder and the valve ports. Initial testing will be needed to verify this assumption. If this is not so then restrictions will be added to the passageways to reduce the back flow of gas from the more distant accumulator volumes.

Force across Main Gas Valve due to Differential Pressure

$$\Delta p = 500 - 0 = 500 \text{ psig}$$

$$A_v = \frac{\pi(D_o^2 - D_i^2)}{4}$$

$$= \frac{\pi(0.56^2 - 0.375^2)}{4} = 0.136 \text{ in.}^2$$

$$F_m = \Delta p A_v = 500 (0.136) = 68 \text{ lbs.}$$

$A_v$  = effective area of main gas valve, in.<sup>2</sup>  
 $D_o$  = 0.56 in.  
 $D_i$  = 0.375 in.  
 $F_{mv}$  = force main gas valve, lbs.

Friction Forces on the Pilot Valve Piston

- Assume major friction is due to O-rings and seals.
- Also assume friction on Block Vee type seals is approximately 60% times that of a comparable size O-ring.

Seal	Parker O-ring	For Piston Groove						F
		$f_c$	$L_p$	$f_n$	$A_p$	$F_c$	$F_H$	
711806	2-113	.7	2.36	23	.19	1.65	4.57	6.02
711825	2-210	.7	3.15	23	.34	2.21	7.82	10.03
--	2-106	.7	1.18	23	.06	1.38	.04	1.42

(From Reference 20)

$$F_c = f_c \times L_p$$

$$F_H = f_h \times A_p$$

$$F = F_c + F_H$$

$$F' = .6(6.02) + .6(10.03) + 1.42$$

$$= 11.05 \text{ lbs.}$$

Note:  $F'$  is applicable when the piston is sliding on the stem. When the two move together  $F' = 11.05 - 1.42 = 9.63 \text{ lbs.}$

<sup>20</sup> O-Ring Handbook OR 5700, Parker Seal Company, Revised August, 1971.

Force Due to Water Pump

$$\text{Area of Pump Piston} = A_{pp} = \frac{\pi(D_o^2 - D_i^2)}{4} = \frac{\pi(.5^2 - .321^2)}{4} = .12 \text{ in.}^2$$

For 500 psi water ( $P_w$ ) the force ( $F_w$ ) would be:

$$F_w = A_{pp} P_w = .12(500) = 60 \text{ lbs.}$$

Friction on Stem due to Seals

(See calculation on Pilot Piston)

Seal	O-Ring	For Piston Groove					
		$f_c$	$L_p$	$f_h$	$A_p$	$F_c$	$F_H$
711803	2-109	.7	1.57	23	.08	1.10	1.84
	2-008	.7	.98	23	.05	.69	1.15

$$\text{Force on stem} = F_s = (.6)2.94 + 1.84 = 3.60 \text{ lbs.}$$

Starting Pressure Force on Back Side of Pilot Piston

$$\text{Area of Pilot Piston Back Side} = A_{ppB} = \frac{\pi(D_o^2 - D_i^2)}{4} = \frac{\pi(1.02^2 - .375^2)}{4} = .67 \text{ in.}^2$$

$$\begin{aligned} \text{Volume displaced by piston movement of .3 in.} &= V_s = A_{ppB} S = .67(.3) \\ &= .201 \text{ in.}^3 \end{aligned}$$

$$\text{Total Volume at end of starting stroke} = V_{s_2}$$

$$V_{s_2} = V_{ps} + V_p + V_{sc}$$

$$V_{ps} = \frac{\pi[D_1^2(.2) + D_2^2(.36)] - D_i^2(.56)}{4}$$

$$= .23 \text{ in.}^3$$

$$V_p = \frac{\pi(D_p^2)}{4} L = \frac{\pi(.093)^2}{4} (.8) = .005 \text{ in.}^3$$

$$V_{sc} = \frac{\pi(D_o^2 - D_i^2)}{4} L_s = \frac{\pi(.437^2 - .312^2)}{4} (.05) = .004 \text{ in.}^3$$

$$V_{s_2} = .23 + .005 + .004 = .239 \text{ in.}^3$$

$$V_{s_1} = .239 + V_S = .239 + .201 = .44 \text{ in.}^3$$

where

$V_{ps}$  = Volume of pilot cycle (start side)

$V_p$  = Volume of passage

$V_{sc}$  = Volume of start cycle

$D_1$  = 1.0 in.

$D_2$  = .80 in.

$D_i$  = .50 in.

$$p_1 V_{s_1} = p_2 V_{s_2}$$

$$p_2 = \frac{14.7(.44)}{.239} = 27 \text{ psia.}$$

$$p_1 = 0 \text{ psig} = 14.7 \text{ psia}$$

$$V_{s_1} = .44 \text{ in.}^3$$

$$V_{s_2} = .239 \text{ in.}^3$$

$$p_2 = 27 - 14.7 = 12.3 \text{ psig.}$$

$$F_{ppB} = \text{force on pilot piston} = A_{ppB} p_2 = .67(12.3) = 8.24 \text{ lbs.}$$

$$\text{Force on starting piston} = A_{sp} p_2 = \frac{\pi(.437^2 - .312^2)}{4} (8.24) = .6 \text{ lb.}$$

#### Pilot Piston Spring

9435K149 (McMaster Carr, Chicago, IL)

O.D. = .720 Wire Diameter = .072

Free length = 1.25 in. Rate = 27.5 lb/in.

Solid Height = .470

Spring Condition	Deflection (in.)	Load (lbs.) = ( $F_{prs}$ )
Initial start	.37	10
End of start	.67	18.4
Main valve open	.77	21.2

Main Gas Valve Spring - Force =  $F_{ms}$   
 9623K11 (McMaster Carr, Chicago, IL)  
 O.D. = .53 I.D. = .28 Free length = 1.0 in.  
 Solid Height = .56 in. Rate = 260 lb/in.  
 Wire .125 x .062

Initial Deflection = .10                          Initial Load = 26 lbs.  
 Final Deflection = .20                              Final Load = 42 lbs.

Area of Pilot Piston Front Face ( $A_{ppF}$ )

$$A_{ppF} = \frac{\pi(D_o^2 - D_i^2)}{4} = \frac{\pi(1.0^2 - .75^2)}{4} = .344 \text{ in.}^2$$

Pressure Sequence

- Gas enters Accumulator and Pilot Piston through needle valve.
- Initial Pressure ( $P_i$ ) to move must overcome pilot piston O-ring friction and force air into starting cylinder.

$$P_i = \frac{F' + F_{ppB} + F_{prs}}{A_{pp}} = \frac{11.05 + 8.24 + 10}{.344} = 85 \text{ psig.}$$

- Pressure to open main gas valve =  $P_o$ ; combined seal friction forces =  $F_f$ .

$$P_o = \frac{F_f + F_w + F_m + F_{prs} + F_{ms}}{A_{ppF}}$$

$$P_o = \frac{(11.05 - 1.42 + 3.60) + 60 + 68 + 18.4 + 26}{.344} = 540 \text{ psig.}$$

Note: this pressure can be varied by skimming to adjust the force on the main gas spring.

- After opening the pressure differential across the main valve decreases. Assuming this reduces to zero then the pressure for wide open would be:

$$P_w = \frac{F_f + F_w + F_{prs} + F_{ms}}{A_{ppF}}$$

$$P_w = \frac{(11.05 - 1.42 + 3.60) + 60}{.344} \quad 21.2 + 42 = 397 \text{ psig.}$$

This would indicate that the valve will first crack open, then will rapidly open to full position.

The pressure at which the valve starts to close will be ( $P_{sc}$ ):

$$P_{sc} = \frac{-F_f + F_{prs} + F_{ms}}{A_{ppF}}$$

$$P_{sc} = \frac{-(11.05 - 1.42 + 3.60) + 21.2 + 42}{.344} = 145 \text{ psig.}$$

The pressure at which the valve closes ( $P_c$ ) will be

$$P_c = \frac{-F_f + F_{prs} + F_{ms}}{A_{ppF}}$$

$$P_c = \frac{-(11.05 - 1.42 + 3.60) + 18.4 + 26}{.344} = 91 \text{ psig.}$$

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CONCLUSIONS AND RECOMMENDATIONS

Based on the literature survey, a review of pertinent data and the preliminary design and calculations it is concluded that a propulsion system can be constructed and demonstrated to meet the requirements of this program.

It is proposed that the prototype pulsejet unit be constructed, that development of the gas generator be carried out and that a demonstration be conducted in accordance with the test plans presented in Appendix B.

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APPENDIX A

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APPENDIX B

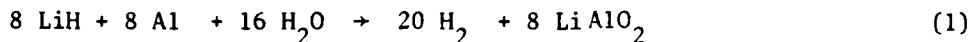
GAS GENERATOR TEST PLAN

and

DEMONSTRATION TEST PLAN FOR THE GAS OPERATED PULSEJET

## GAS GENERATOR TEST PLAN

Our literature survey has failed to disclose any data on the rate at which hydrogen is released in the reaction



DeVries gives some data for



which shows that the reaction rate increases with pressure. We would also expect the rate to double for every  $10^\circ \text{ C}$ , and for a substantial amount of heat to be liberated.

In order to quantize these effects it is necessary to initiate the reaction in a pressure vessel and monitor pressure with some kind of dynamic recorder, utilizing an apparatus of the type shown in Figure B.1.

Our calculations indicate that a full fifteen minutes run at 3 lb. average thrust (six inches total stroke in the pulsejet) requires an operating speed of 1.56 Hz and a total gas charge of 2.16 grams at 500 psig. The total fuel charge is thus 30.14 gm and the heat released by the reaction is 430 Btu, corresponding to a rate of 1714 Btu/hr. This heat flow rate is easily managed if the outside of the reactor is liquid (water) cooled but could cause problems in the lab without special cooling provisions.

We plan to monitor flask temperature as well as recording the pressure dynamically. We initially assume that the reaction rate ( $k$ ) will depend primarily on temperature, in accordance with the Arrhenius equation, but DeVries has shown that the  $\text{LiH} + \text{H}_2\text{O}$  reaction also increases with pressure. If this is so for the  $\text{LiAlH}_4 + \text{H}_2\text{O}$  reaction, then we need to quanize this in order to permit the reaction rate equation to be appropriately modified.

Since the purpose of these tests is to determine the constants in the Arrhenius equation, so that temperature and pressure constraints can be defined for the reactors, measurements of rate will be made at temperatures of  $0^\circ$ ,  $32^\circ$ ,  $60^\circ$ , and  $100^\circ \text{ F}$ , and pressures of 0, 50, 100, 200, and 500 psig.

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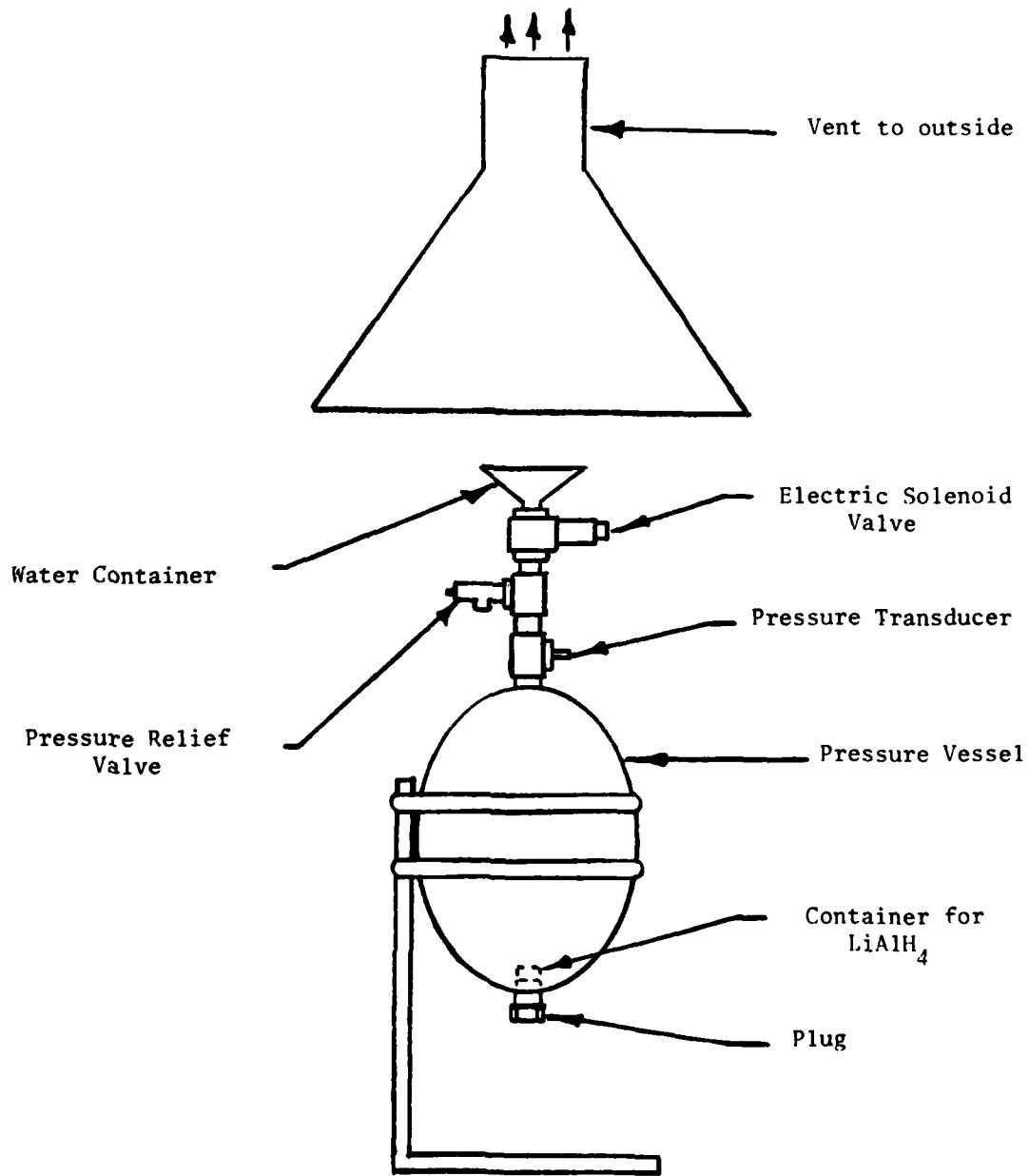


Figure B.1. Test set-up for determining reaction rate.

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ENGINE TEST PLAN

The exhausting hydrogen represents a fire hazard in a normal lab environment. Also, while the proposed fuel ( $\text{LiAlH}_4$ ) is harmless when loaded into the reactor, recharging requires sophisticated equipment. And since it is unlikely that a demonstration test can be completed in fifteen minutes, it is proposed to employ a separate gas source, such as a compressed nitrogen bottle for most of the demonstration. Hydrogen will be employed for a few seconds merely to demonstrate that its lower atomic weight does not influence the engine's ability to operate.

Thrust measurement is notoriously difficult with a pulsejet because of its transient nature. And since the mission is to deploy a line of transducers underwater, an adequate test would be to deploy a 500 foot line in water. This can best be accomplished on the surface (like the NOSC tests) since we are not then faced with the complications of guidance. It is therefore proposed to fashion a simple boat, large enough to hold a small gas cylinder (at least 40 in<sup>3</sup> capacity) with the pulsejet mounted underneath. The deployment of 500 ft of line will then be demonstrated in a sheltered body of water, or, given inclement weather, in an indoor swimming pool, the model being turned around at each end, in the latter case.

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APPENDIX C

DETAIL DRAWINGS OF THE PULSEJET

8

7

6

5

D

3

329  
921  
921  
329  
921

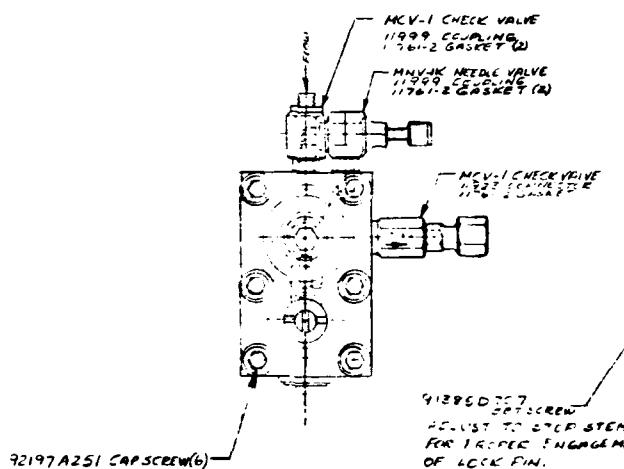
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2-O-RING —  
209R18-1 POPPET  
71625 SEAL  
711806 SEAL

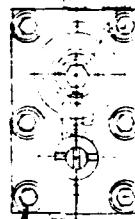
962  
962329  
2-0  
2-0

329-1  
2-OCE O-RING  
711803 SEAL

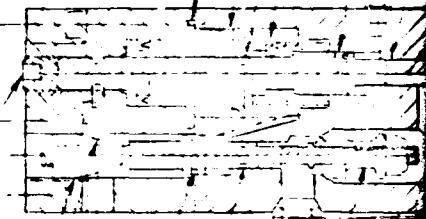
329



912860357  
ADJUST TO STEM  
FOR TOPPER ENGAGEMENT  
OF LOCK PIN.



912860357  
ADJUST TO STEM  
FOR TOPPER ENGAGEMENT  
OF LOCK PIN.



2-O-RING  
—  
29422-1 PIN  
748K50 SPRNG  
—  
29422-1 CAM  
ADJUSTS PIN IS  
DEACTIVATED FROM  
MAIN STEM WHEN  
LEVER IS PULLED.  
LOCK PIN IS  
SLATED, LOCK WITH  
THENOLOCK SEALANT.

29422-1  
—  
748K50 SPRNG  
—  
29422-1 CAM  
ADJUSTS PIN IS  
DEACTIVATED FROM  
MAIN STEM WHEN  
LEVER IS PULLED.  
LOCK PIN IS  
SLATED, LOCK WITH  
THENOLOCK SEALANT.

1. -1 ASSEMBLY IS MADE OF CRES. STEEL & INTENDED TO  
OPERATE AT APPROX 600 PSIG.

-2 ASSEMBLY IS IN ACETYLENE FOR DEVELOPMENT AND  
SHOULD NOT BE OPERATED ABOVE 100 PSIG.

NOTES:

↑

37-3L

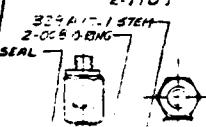
ZONE	LTR	DESCRIPTION	DATE	APPROVED

329A26-1 CAP ASSY  
 92197A240 CAP SCREWS(2) } FOR 1  
 92197A240 CAP SCREWS(4) } ASSY  
 329A26-3 CAP ASSY } FOR 3  
 92197A299 CAP SCREWS(6) } ASSY

2-010 O-RING  
 329A15-1 SPACER (-4051)  
 329A23-3 SPACER (-4051)

7623K11 SPRING (-1ASW)  
 7634K77 SPRING (-3ASW)

329A16-1 POPPET  
 2-O-RING  
 2-110 O-RING



2-115 O RING

3-150AT9 CAP SPACER  
 (1.17 TO 1.22 INCHES)  
 3-141-1 CHECK VALVE ASSY  
 1-110-1 STEM  
 SEAL ELL WITH 1/4-20 UNF  
 SILICONE KITMINGE

329A19-1 POPPET  
 2-O-RINGS  
 76628P011 NUT  
 401-17 NUT & VALVE SEATS WLT  
 AFTER START POSITION PISTON  
 DISENGAGES FROM BORE.

1-1	90634A011	NUT			
1-1	92199A709	CAP SCREW			
6-6	92197A251	CAP SCREW			
6-4	92197A249	CAP SCREW			
2	92197A260	CAP SCREW			
1-1	913PE5267	SET SCREW	M'MASTER CARR		
1-1	9425K50	SPRING	ELMHURST, IL. 60126		
1-1	9425K109	SPRING			
1-1	9425K77	SPRING			
1	2-010	O-RING			
1	7118C2	SEAL	B-70V VEE SEALS		
1-1	711PC3	SEAL	CR INDUSTRIES		
1-1	711B25	SEAL	EGUN, IL. 60130		
1-1	2-024	O-RING			
1-1	2-110		TACKER SEAL COMPANY		
2-2	2-110		CLARK ST. 711-9C280		
1-1	2-014		1-TELE (PMI) INC. COMMERCIAL		
1-1	2-011		SHAW & MCKEE CO. INC. LUPHETEC		
2-2	2-010	O-RING			
2-2	2-110				
2-6	1-70112	SPIGOT			
1	1-7013	CONNECTOR			
1-2	1-8057	COUPLING	CLIPPED - STYLUS LABORATORY, INC		
1-1	1-NN-1X	NEEDLE VALVE	CINCINNATI, OH. 45284		
1	1-NN	FLOW VALVE			
1-1	3-1-127-1	CHECK VALVE ASSY			
1	3-1-126-2	CAP BODY			
1	3-1-127-1	CAP ASSY			
1	3-1-125-2	HEAD			
1	3-1-125-1	HEAD			
1	3-1-124-2	BODY			
1	3-1-124-1	BODY			
1	3-1-127-2	SPACER			
1	3-1-128-1	SPACER			
1	3-1-122-1	VALVE			
1-1	3-1-120-1	STEM			
1-1	3-1-120-1	CLIP			
1-1	3-1-119-1	PIN			
1-1	3-1-115-1	PISTON			
1-1	3-1-115-1	PISTON			
1-1	3-1-116-1	STEM			
1-1	3-1-116-1	PISTON			
-2		PLATE SET ASSY (FRASER MFG.)			
-1		PLATE SET ASSY (CCCO ST. 111)			
CODE	PART NO.	STOCK SIZE AND MATERIAL OR VENDOR	SPECIFICATION	UNIT WT	ITEM NO
IDENT NO	DESCRIBE & DRAWN BY				

IN THIS OTHERWISE SPECIFIED  
 DIMENSIONS ARE IN INCHES  
 DO NOT SCALE

**TOLERANCES**

2 PLACE 3 PLACE ANGLES

± .005 ± .005 ± 1°

**CONTRACT NO**

SIGNATURES DATE

DRAWN BY: J. J. MAZ

CHECK

ENGINEER

**PAYNE INC.**

ADDRESS: 1000 1/2 10TH

PLATE SET,  
 345 FLOWER ST.

**DESIGN ACTIVITY APPROVAL**

SIZE CODE IDENT DRAWING NO

REV

LTR

REV C-1  
 D-1

BY: J. J. MAZ

DATE: 10/10/74

SCALE

WT

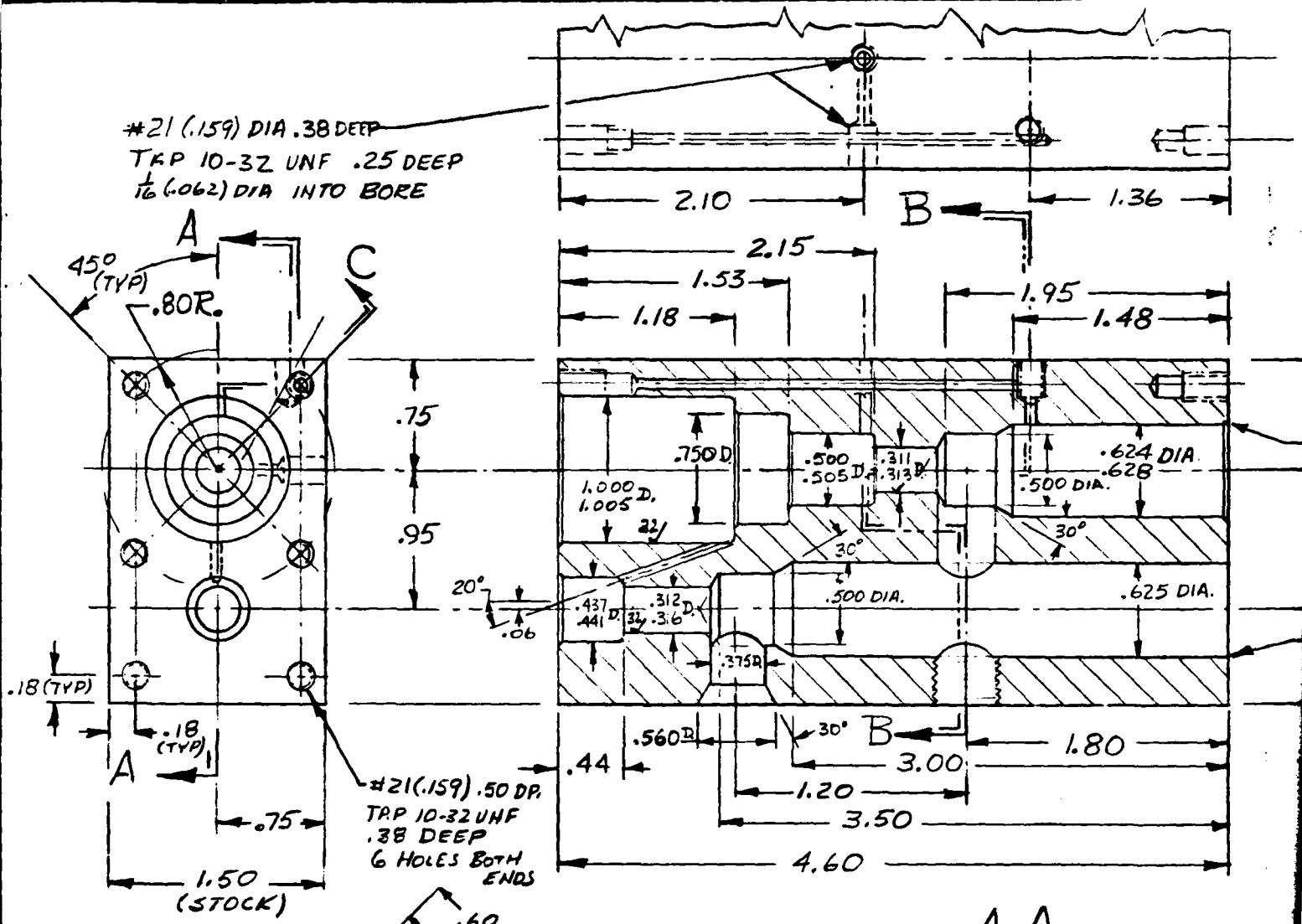
SHEET

OF

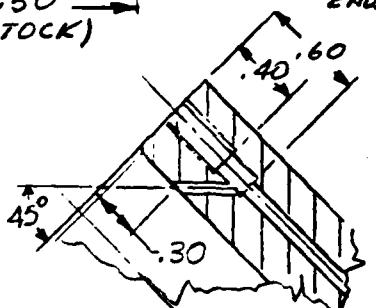
Copy

permit

C-1



SECTION A-A

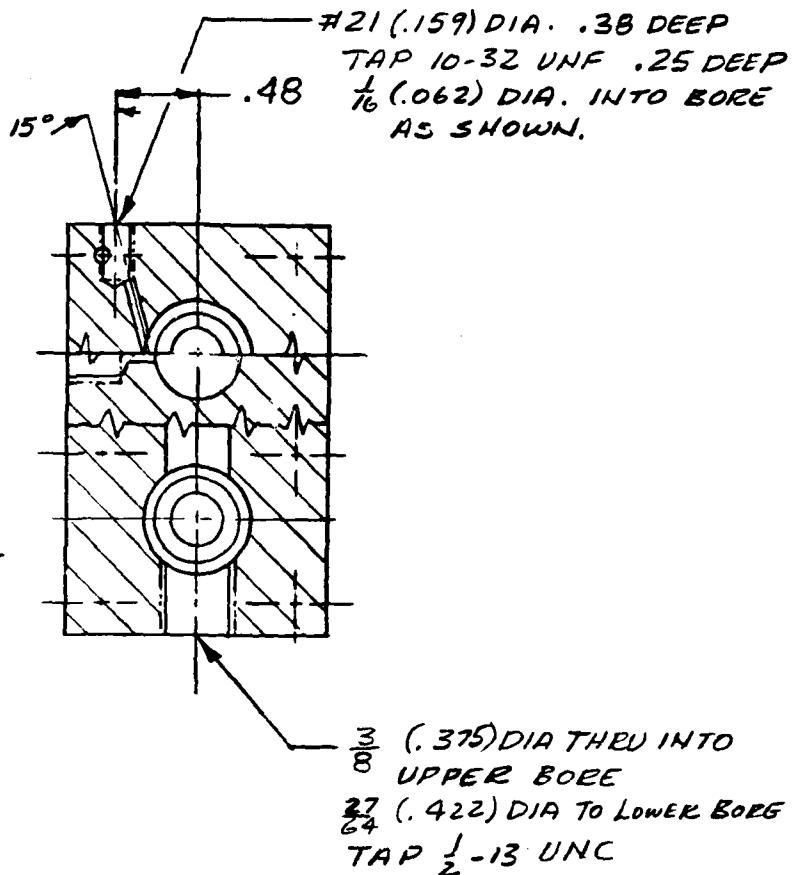


PARTIAL SECTION C

PART NO.	
ODD DASH NO.	EVEN DASH NO.
UNLESS OTHER	
DIMENSIONS:	
TOLERANCE:	
TOLERANCE:	
MEET DIM.	
BURR ALL	
CORNER	
S. SPOTF.	UP TO 1.5
GREATER	
MATERIAL	
ABOVE: NO. REQ/ASSY NOTED	
BELLOW: N.A. & PROJ.	

## REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
-C				

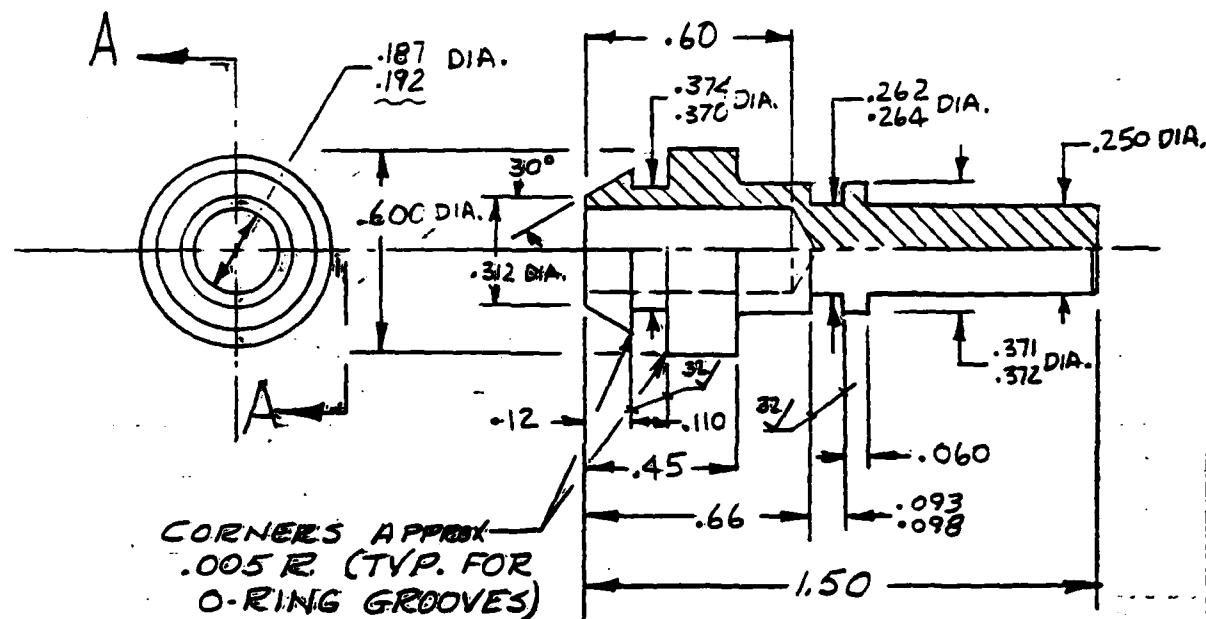


PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.	UNIT WT.	ZONE
-C	EXT.	1.50 PLATE ACRYLIC	CLEAR MIL-P-2103		
-1	BODY	1.50 PLATE CRES. STL	TYPE 304 1.5521		
PART NUMBER		PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.	UNIT WT.
ODD DASH NOS. SHOWN EVEN DASH NOS. OPPOSITE UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCE ON XX DIM. ± .03 TOLERANCE ON XXX DIM ± .01 TOLERANCE ON ANGLES ± 15° MEET DIMS. BEFORE PLATING BURR ALL EDGES CORNER RADII ON C'BORES & SPOTFACES: UP TO 1.25 DIA. GREATER THAN 1.25 .003 MAX. PER MIL-STD 10		CONTRACT NO.	<i>Payne, Inc.</i>   ANNAPOLIS, MARYLAND 21401		
		SIGNATURES & DATE			
		DRAWN NE-MAR-18 10-28-81			
		CHECK			
		STRESS			
		WEIGHT			
		PROJ.	SIZE	FED. CODE NO.	
		CUSTOMER	B	57433	329B24
			SCALE:	FULL SIZE	WT: EST: ACT: SHEET / OF 1

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



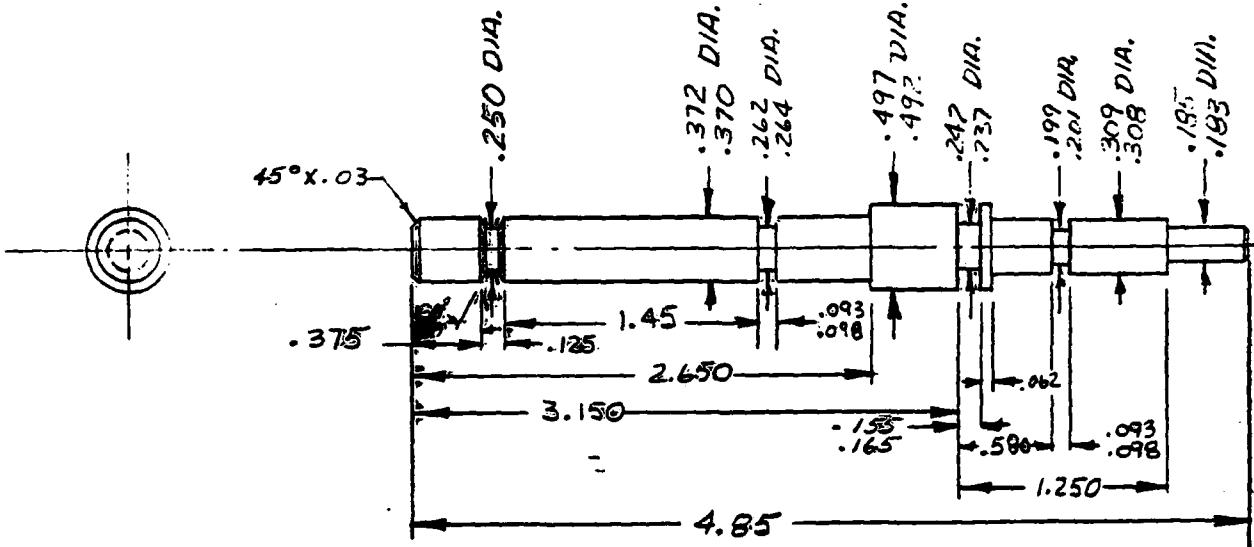
PARTIAL SECTION A-A  
NOTE - TWICE SIZE

329A16-1 P75	-1	POPPET	.75 DIA BAR CRES. STL. TYPE 303 OR 316LN	STOCK SIZE & MATERIAL SPEC. OR CODE I.D. NO.	UNIT OF MEAS.
	PART NUMBER	PART NAME	STOCK SIZE & MATERIAL SPEC. OR CODE I.D. NO.		
000 BACK NO. SHOWN EVER BACK - PEL. DIFFERENT UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOL. ON L.S. DIA. ± .010 TOL. ON JAW DIA. ± .010 TOL. ON ANGLES ± 1° MEET DIMS. BEFORE PEARLING SURF ALL 2000 CORNER RASH ON C'NERS & SPOTFACES UP TO L25 DIA. .000 GREATER THAN L25 .000 MAX PERMITTED 10		CONTACT NO.	Payne Inc. Anapolis, Md. 70801		
		MANUFACTURED BY DATE			
		DRILLED: November 10-27-81			
		EXCESS			
		STRESS			
		WEIGHT			
		SIZE	PLC. CODE NO.	CODE	
		A	57433	57433	
		CUSTOMER			
			SCALE	WT.	EST.
			TWICE SIZE	ACT.	SHRINK 10%

## REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



1. REMOVE SHARP CORNERS APPROX. .005 R.  
ALL RADII .005/.015.

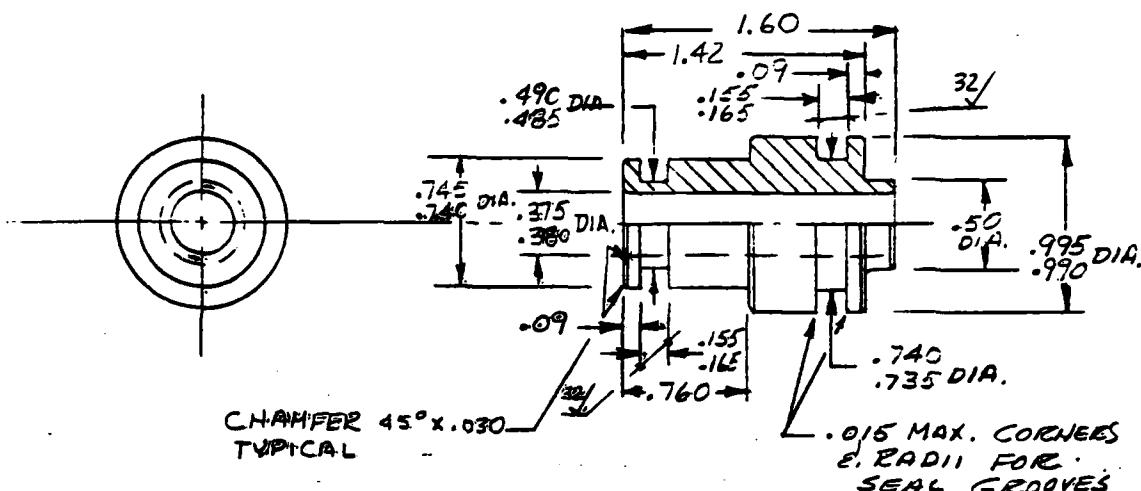
NOTES:

PART NUMBER  329A171-X  121 531 0275	-1	STEM	.560 DIA. CRES. STL.	TYPE 3C3 - EQUIL.	
	PART NAME	SHOCK SIZE & MATERIAL	SPEC. OR CODE IS1NL	UNP.	
PART NUMBER 329A171-X  121 531 0275		COMPONENT NO.  SUBCOMPONENT NO. 10-2781	Payne Inc. Anapolis, Md. 21403		
DIMENSIONS ARE IN INCHES TOL. ON .250 DIA. ± .015 TOL. ON .375 DIA. ± .010 TOL. ON ANGLES ± 1° HEAT DIA. BEFORE PLATING SHRINK ALL GEOMETRIES CORNER RADII OF C-TORS D. SPOTFACE UP TO 1.25 DIA. .005 GREATER THAN 1.25 .005 MAX PITCH STD 10		COMPONENT NO.  SUBCOMPONENT NO. 10-2781	STEM, MAIN AND PILOT VALVE		
PROL		STL	U.S. CODE NO. A 57433	329A17	CODE L77
CUSTOMER		FULL SIZE	WT.	EST. ACT.	SWEEF / SP

## REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30

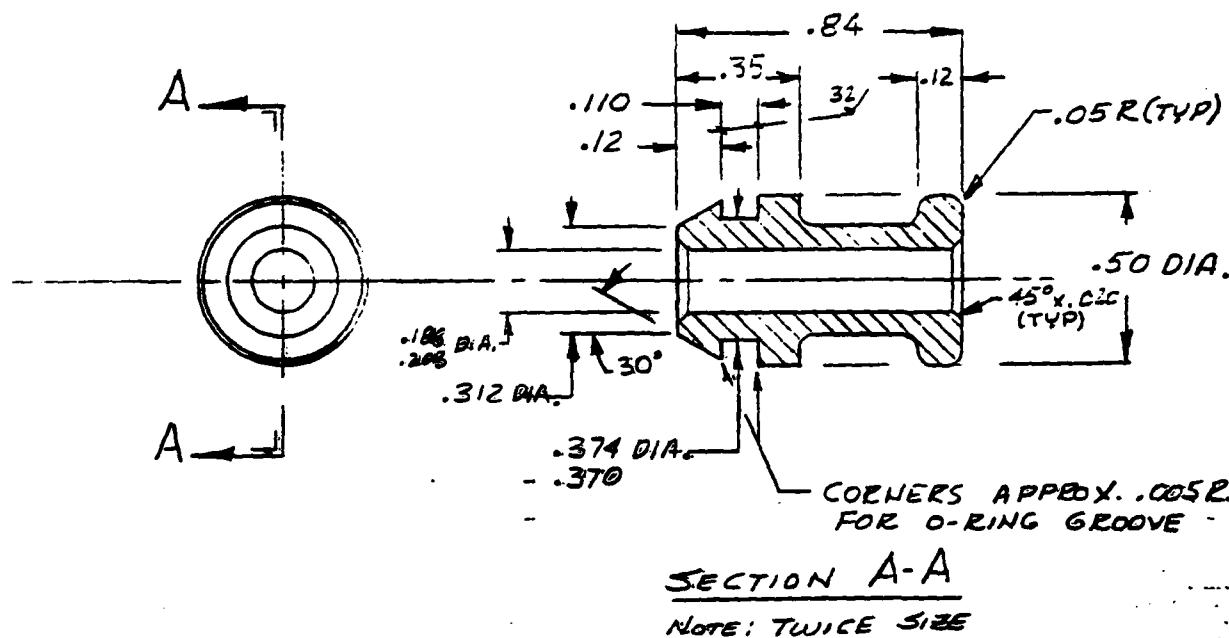
PARTIAL SECTION

329A/8-1	-1	POPPET	1.00 DIA. CRES. STL.	TYPE 303 OR EQUIV.
	PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE IDENT.
ONE DASH NO. SHOWN EVEN DASH NO. OPOSITIVE UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOL. ON .100 DIA. .010 TOL. ON .375 DIA. .010 TOL. ON ANGLES ± 4° MEST DIA. BEFORE PLATING DIA. ALL SURFACES COMMON MACH. OR C'POSED & SPOTFROZEN UP TO 1.25 DIA. GREATER THAN 1.25 MAX PERMIT STD 10: 63		PAYNE INC. Annapolis, Md. 21401 POPPET, PILOT VALVE		
CUSTODIAN NO. DRAWING NO. 10-27-81 DESIGNER APPROVED DATE WORKMAN INSPECTOR PROD. CUSTOMER		SIZE      FEAT. CODE NO.      329A 18 A      57433 SCALE      FULL SIZE      WT.      EST. ACT.      SHEET / DAY		

## REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30

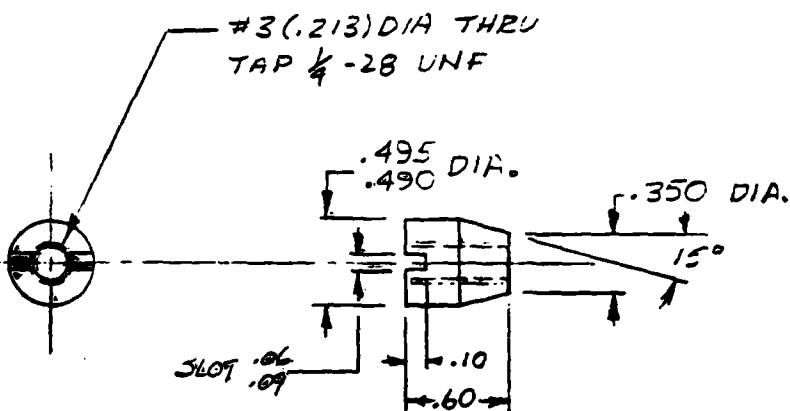


-1	P-POPPET	.50 DIA CRES. STL.	TYPE 303 GEOMETRY
PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE I.D. NO. <i>329A19</i>
ONE SIDE NEED SHOWN TOP SIDE NOT OPPOSITE VALVE DIMENSIONS SPECIFIED DIMENSIONS ARE IN INCHES TOL. ON TOTAL L.G. .03 TOL. ON TOTAL HGT. .040 TOL. ON ANGLES ± 1° HEAT SHOT BEFORE PLATING SHIP ALL PLATED COMMIT RISK ON C-SPOT O. SPOTSHOT UP TO 1.50 DIA. .000 GREATER THAN 1.50 .000 MAX PERCENT STD. 10		Annapolis, Md. <b>Payne Inc.</b> 329A19	
DRAWN BY <i>John L. Payne</i> DATE <i>10-27-81</i> DESIGNED BY <i>John L. Payne</i> REV. <i>1</i> ENGINEERED BY <i>John L. Payne</i> APPROVED BY <i>John L. Payne</i> CUSTODIAN <i>John L. Payne</i> CHECKED BY <i>John L. Payne</i> INSPECTOR <i>John L. Payne</i> DRAWN BY <i>John L. Payne</i>		POPET , EXHAUST VALVE	
329A19-1	A	57433	329A19
	SCALE	WEIGHT NO.	CHECKED BY
	TWICE SIZE	WT. EST. ACC.	SHEET 1 OF 1

## REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30

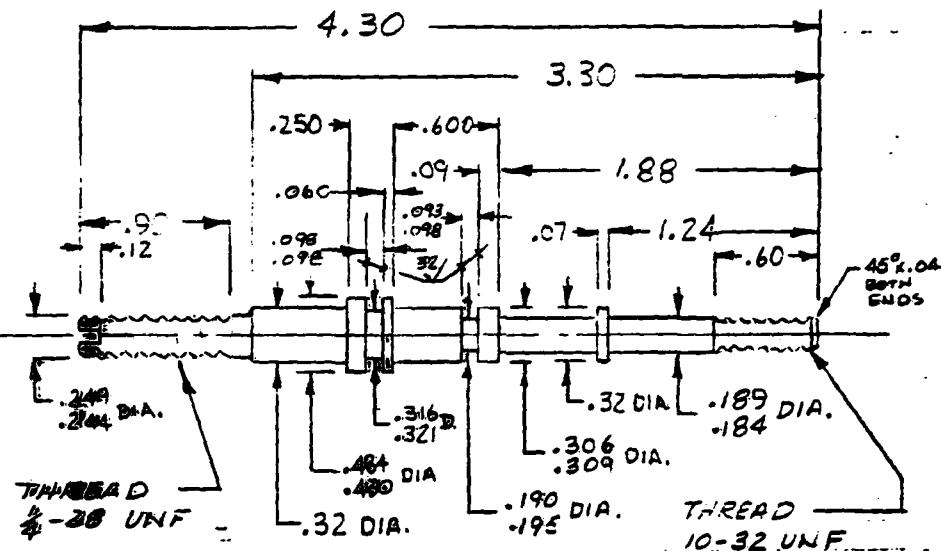


C-7 329A20-1	-1	CAM	.500M CRES. STL	TYPE 303 OR EQUIV.
	PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE IS. NO.
O.D. DASH HOLE SHOWN. EVEN SLOTS HOLE OPPOSITE UNLESS OTHERWISE SPECIFIED DIMENSIONS AND TOLERANCES TOL. ON .490 DIA. ± .0005 TOL. ON .495 DIA. ± .0005 TOL. ON ANGLES ± 5° HOLE SIZES, BORES, PLATING SURF ALL. RECOMM. CORNER RADIUS ON C'NERS; O.D. SPECIFIED UP TO 1.25 IN. GREATER THAN 1.25 MAX PULL-IN STD. 10  <b>67</b>		DRAWING NO. DRAWN BY CHECKED BY APPROVED BY DESIGNER DATE PAYNE INC. Annapolis, Md. 20401  <b>CAM, VALVE STEM LOCK</b>	329A20-1 PAYNE INC. Annapolis, Md. 20401  <b>CAM, VALVE STEM LOCK</b>	
		DATE PAYNE APPROVED DRAWN FULL SIZE WT. EST. ACT. SHEET 1 OF 1		
		A 57433	329A20	

## REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



1. CORNERS & RADII  
.005 APPROX.

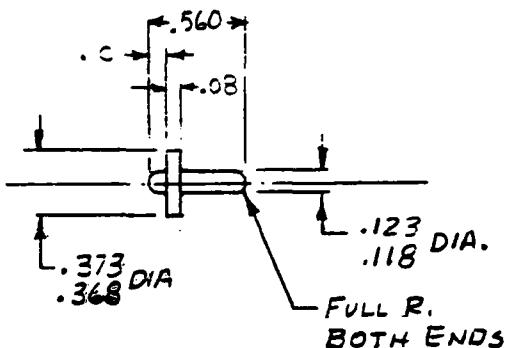
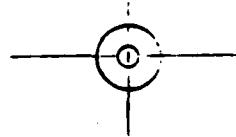
NOTES:

PART NUMBER 329A21	-1	STEM	.50 DIA CRES. STL	TYPE 303 OR EQUIV.
	PRINT NUMBER	SECTION SIZE & MATERIAL	SPEC. OR CODE I.D. NO. UNIT	
ONE SIDE HOLE SHOWN EVEN SIDE HOLE OPPOSITE UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOL. ON .300 DIA. .015 TOL. ON .300 DIA. .015 TOL. ON ANGLES IS X MUST CHAMF. BEFORE PLATING DRAWD. ALL. BURRS. CORNERS RADIUS OF C-TURNS & SPECIFIED UP TO 1.25 DIA. .005 GREATER THAN 1.25 .005 MAX PERMITTED 10		DRAWN BY SIGNATURE & DATE PAYNE INDUSTRIES 10-26-68 CHECKED APPROVED WEIGHT	Payne Inc. 329A21 STEM, EXHAUST VALVE	
PROL:	SIZE A	PUB. CODE NO. 57433	329A21	ONE COPY
CHARTED	SCALE FULL SIZE	WT. EST. ACT.	Sheet 1 of 1	

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



1. CORNERS & RADII  
APPROX .015.

NOTES:

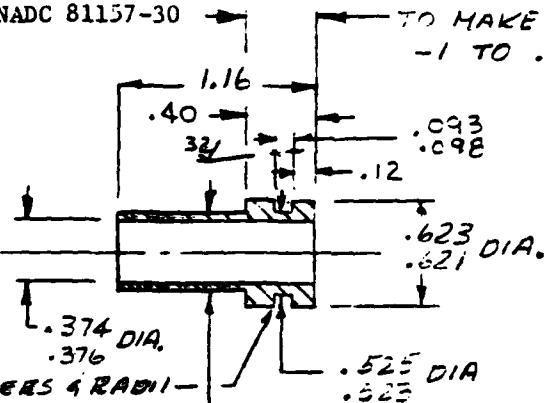
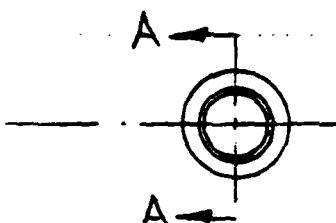
PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.	
			COMPONENT NO.	LINE
-1	PIN	.50 DIA. CRES. STL.	TYPE 303 OR 80WIK	1
DRAWN BY: PAYNE INC.		APR 22, 1968		
CHECKED BY: PAYNE INC.		APR 22, 1968		
APPROVED BY: PAYNE INC.		APR 22, 1968		
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOL. ON .50 DIA. ± .03 TOL. ON .373 DIA. ± .010 TOL. ON .368 DIA. ± .005 MEET DIA. BEFORE PLATING. TURN ALL EDGES CORNER RADIUS OF C'NERS & SPOTFACES UP TO L25 DIA. .002 GREATER THAN L25 .005 MAX PERIOD-STD 10		<b>Payne Inc.</b> <b>PIN, MAIN VALVE STEM LOCK</b>		
DRAWN BY: PAYNE INC.		PEL. CODE NO.: 57453	329A 22	CHEK LST
CUSTODIAN		FULL SIZE	MR.	REC. REC'D.
				1/01

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30

TO MAKE -3 TRIM  
-1 TO .40 DIM.



CORNERS & RABBI-  
FOR O-RING GROOVE  
APPROX. .005 .450 DIA.

SECTION A-A

DETAIL - I

**Payne Inc.**

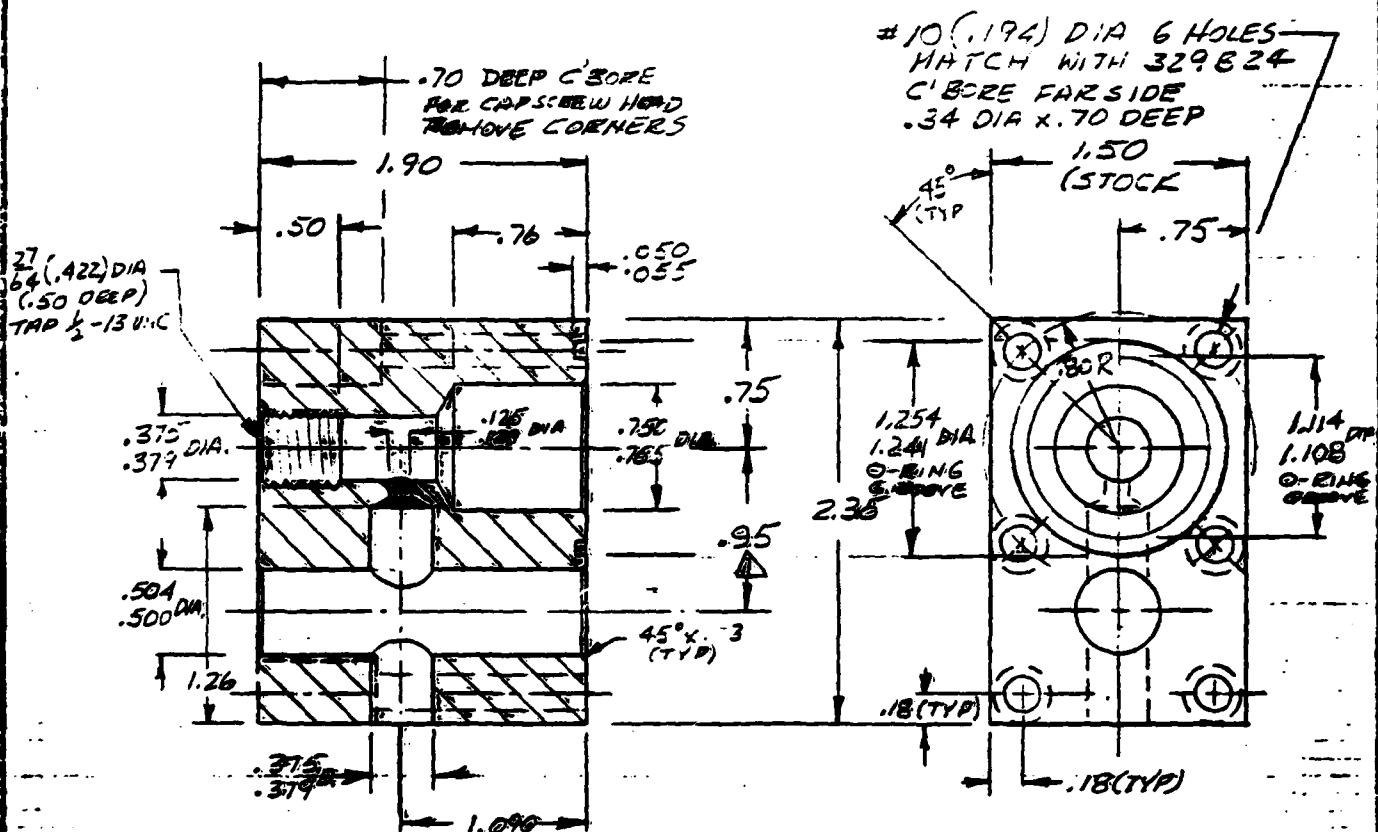
## SPACER, ACCUMULATOR

ACCE	FILE COOK REC.	329 A 23	CHINE 227			
A	57433					
FULL SIZE		WT:	EXT:	NET:	STOCK #	1

## **REVISIONS**

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



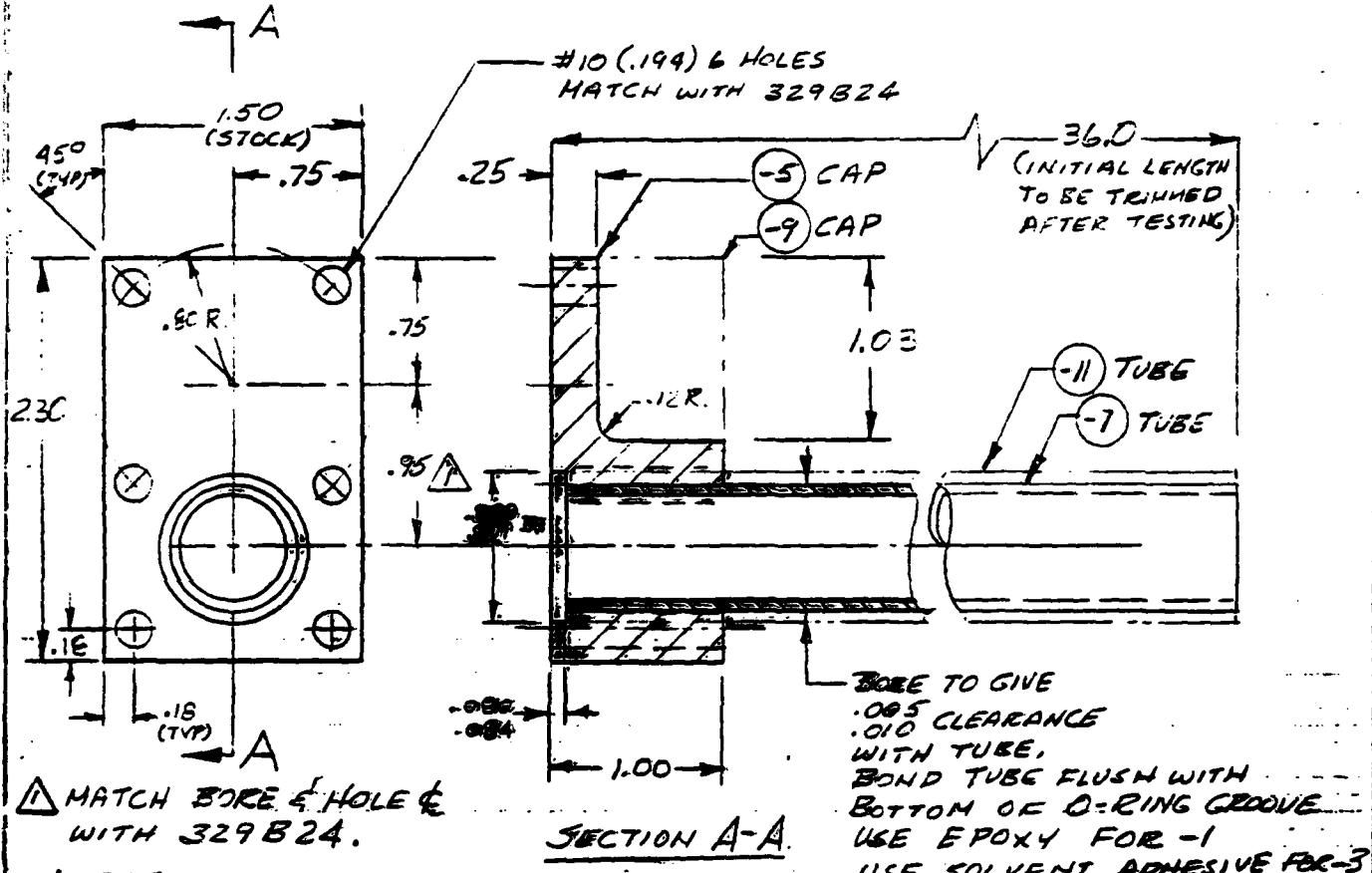
MATCH BORE & WITH  
329 B24.

## NOTES:

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



**△ MATCH BORE & HOLE &  
WITH 329 B24.**

**SECTION A-A**

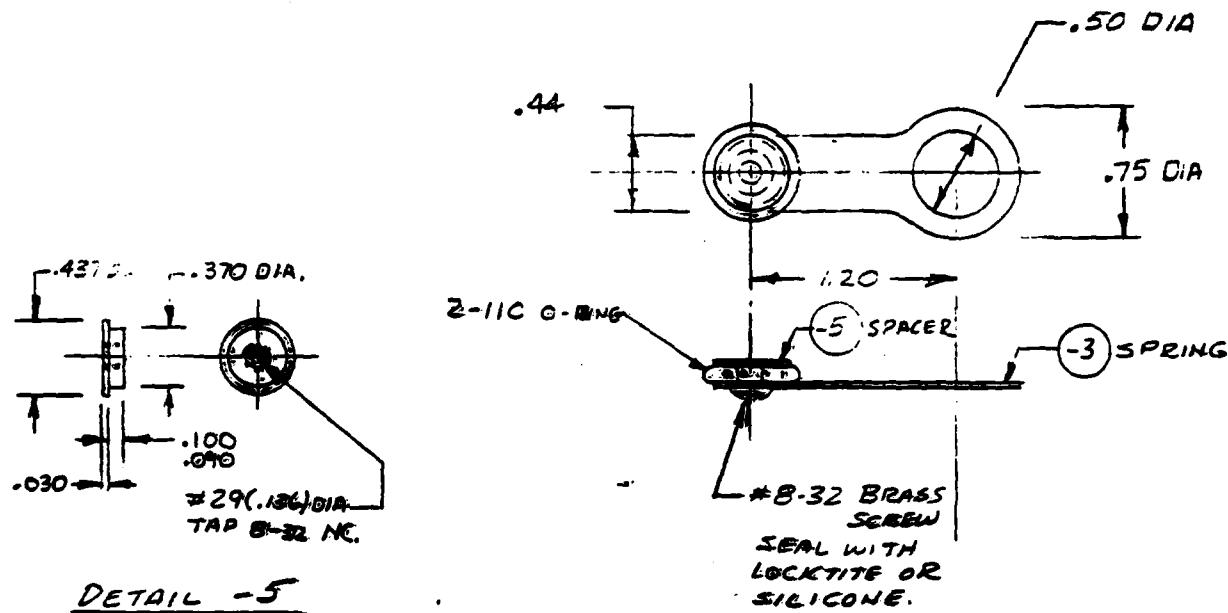
**NOTES:**

PART NUMBER	PART NAME	SHOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.
-11	TUBE	.516 O.D. X .125 WALL TUBING ACETYLIC MIL-P-21145	
-9	CAP	1.50 PLATE ACETYLIC CLEAR MIL-P-21145	
-7	TUBE	.75 O.D. X .065 WALL TUBING CRES. STL. TYPE 304 OR EQUIV	
-5	CAP	1.50 PLATE CRES. STL. TYPE 304 OR EQUIV	
-3	CAP ASSY		
-1	CAP ASSY		

## REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



1. REMOVE ALL SHARP EDGES.

NOTES

PART NUMBER	PART NAME	SHANK SIZE & MATERIAL	SPEC. OR CODE ID. NO.
#8-32	BRASS SCREW		
Z-110	O-RING	PLASTIC OR EQUIV. BUNSON	SHANK A HOLLOW TUBE DIA. 1/4 IN.
-5	SPACER	.50 DIA.	BRASS BAR
-3	SPRING	.010 SHIM STOCK	BRASS
-1	VALVE ASSY		
PART NUMBER		COMMITTEE NO.	
329A27-1		SUBMITTED BY DATE	
		MAY 10, 1981	
		INITIALS	
		REVIEWED	
		APPROVED	
		Payne Inc.	
		VALVE ASSY., EXHAUST CHECK	
ONE SIDE NO. SHOWN OPPOSITE SIDE NO. SHOWN UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOL. ON .30 DIA. : .03 TOL. ON .370 DIA. : .03 TOL. ON ANGLES : .03 NET DIA. BEFORE PLATING SHOW ALL SHIMS CUT OFF RADIUS OF 1/16 IN. STOPFACES UP TO 1.25 DIA. .005 GREATER THAN 1.25 .005 MAX PERCENT GROSS 10%		FILE NO. 57433	
		329A27	
		FULL SIZE	
		C-13	